Toxic Chemicals in the Great Lakes and Associated Effects

VOLUME I — Contaminant Levels and Trends

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TOXIC CHEMICALS IN THE GREAT LAKES
AND
ASSOCIATED EFFECTS

VOLUME I
CONTAMINANT LEVELS AND TRENDS

March 1991

ENVIRONMENT CANADA
DEPARTMENT OF FISHERIES AND OCEANS
HEALTH AND WELFARE CANADA

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AUTHORS AND CONTRIBUTORS

The Steering Committee extends thanks to the primary authors and the contributors to the two volumes of this report. We would also like to thank those who participated in the review process. Those individuals are acknowledged at the end of each part of the report.

Authors

R.J. Allan	National Water Research Institute Environment Canada
A.J. Ball	National Water Research Institute Environment Canada
V.W. Cairns	Great Lakes Laboratory for Fisheries and Aquatic Sciences Department of Fisheries & Oceans
G.A. Fox	Canadian Wildlife Service Environment Canada
A.P. Gilman	Environmental Health Directorate Health and Welfare Canada
D.B. Peakall	Canadian Wildlife Service Environment Canada
D.A. Piekarz	Great Lakes Environment Office Environment Canada
J.C. Van Oostdam	Environmental Health Directorate Health and Welfare Canada
D.C. Villeneuve	Environmental Health Directorate Health and Welfare Canada
D.T. Williams	Environmental Health Directorate Health and Welfare Canada

Contributors

C. Bishop	Canadian Wildlife Service Environment Canada
R.W. Brecher	Eco Logic, Inc.
W.D. Clements	Eco Logic, Inc.
J. Chouinard	Consultant
T.E. Colborn	World Wildlife Fund The Conservation Foundation Washington, D.C.
J.M. Cooley	Great Lakes Laboratory for Fisheries and Aquatic Sciences Department of Fisheries and Oceans
K. Davies	Ecosystems Consulting Inc.
S. Kennedy	Canadian Wildlife Service Environment Canada
K.L. Maus	Environmental Health Directorate Health and Welfare Canada
R.J. Norstrom	Canadian Wildlife Service Environment Canada
D.V. Weseloh	Canadian Wildlife Service Environment Canada
D.M. Whittle	Great Lakes Laboratory for Fisheries and Aquatic Sciences Department of Fisheries and Oceans

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INTRODUCTION

The increased commercial production and widespread use of synthetic toxic chemicals and metals since the 1940s have resulted in the contamination of the environment. While the presence of persistent toxic chemicals in the Great Lakes has been known for some time, concerns have been directed in recent years towards the environmental and human health effects of these chemicals.

During the past two and a half years, Environment Canada, the Department of Fisheries and Oceans, and Health and Welfare Canada have worked together to compile the scientific literature on the levels, trends and effects of persistent toxic chemicals in the Great Lakes basin. This has resulted in a two volume technical document entitled *Toxic Chemicals in the Great Lakes and Associated Effects*. Volume I of this report is divided into four parts. It summarizes data on the concentrations of toxic chemicals in water and sediments, invertebrates and fish, wildlife, and humans. Volume II also contains four parts. It reviews what is known about the effects of persistent toxic chemicals on fish, wildlife and people and presents a concluding synthesis which interprets the significance of the levels and effects information in the two volumes. Each part of the report begins with an executive summary.

Based on our knowledge of chemicals and their toxicology, a pattern is emerging that suggests that persistent chemicals in the environment have a significant effect on fish and wildlife species. We still know very little about the effects of a person's lifetime exposure to toxic organic chemicals and metals. Despite some uncertainties, it is clear that toxic chemicals are a threat to the entire ecosystem. As a result, the principle of "virtual elimination" of persistent toxic substances from the lakes has been adopted in the Canada-US Great Lakes Water Quality Agreement. The national governments of both countries together with the province of Ontario, the eight Great Lake states and the large municipalities are moving towards this goal using the regulatory processes, pollution prevention strategies and public education. In the meantime, government programs continue to monitor the health of the ecosystem, assess the extent to which it is impaired by toxic chemicals and develop means to reduce the impact of exposures.

TOXIC CHEMICALS IN THE GREAT LAKES AND ASSOCIATED EFFECTS

VOLUME I PART 1

CONCENTRATIONS OF CONTAMINANTS IN WATER AND SEDIMENTS

EXECUTIVE SUMMARY

This part of the report reviews the available information on concentrations and trends of chemicals in Great Lakes water and sediment. Published reports have been used whenever possible and uninterpreted data have not been included.

The most recent data on chemicals in water are the most reliable and show that ambient concentrations are in the low parts per trillion range. This is much lower than concentrations measured in the past. Presently, most concentrations of toxic chemicals in water from the Great Lakes are below the Great Lakes Water Quality Agreement objectives.

Data on chemical concentrations in sediment cores indicate that the major loadings of persistent toxic chemicals to the Great Lakes aquatic ecosystem took place between the 1950s and the early 1970s. Major influxes of several individual chemicals occurred several years before they were first detected in biota. Concentrations of chemicals have decreased and are lower than they were 10 to 15 years ago. In some lakes, these decreases in sediment concentrations have been dramatic and correlate with bans or restriction on the manufacture and use of chemicals including PCBs and mirex.

Lakes Ontario, Michigan, and Erie are the most chemically contaminated of the Great Lakes. Lake Superior is the least contaminated. The chemical concentrations are affected by physical characteristics of the lakes and connecting channels and the types of source. The atmosphere is relatively a greater source of most of the critical pollutants (e.g., PCBs, DDT and alkyl lead) to the upper Great Lakes than to the lower lakes. The large surface areas and drainage basins of the upper lakes are major contributing factors. Conversely, the lower lakes receive larger inputs from their main tributaries, industries, municipalities and agriculture than the upper lakes.

Concentrations of contaminants in water are higher in the nearshore areas. In contrast, higher concentrations are found in sediments in the depositional basins, harbours and deltas. These include Saginaw, Georgian, Duluth-Superior and Green Bays, western Lake Erie and adjacent to the Niagara River in Lake Ontario. In the connecting channels, higher levels are usually found along the shore downstream from sources. Concentrations of some chemicals in the sediments are still increasing along the St. Clair-

Detroit River corridor and the Niagara River. Spills are a major problem in the St. Clair River.

Although 362 xenobiotic chemicals have been detected in the waters of the Great Lakes, no new ubiquitous, persistent and highly toxic contaminants have been detected since 1982. Future control actions will have to take into account point sources that have not yet been adequately controlled (e.g., sewage treatment plants) and non-point sources of chemicals, such as the atmosphere; chemicals remobilised from contaminated sediment; agricultural, forestry and urban runoff sources; and groundwater.

In the 1978 Great Lakes Water Quality Agreement, Canada and the U.S. agreed to the virtual elimination of all persistent toxic substances from the Great Lakes with an eventual goal of zero discharge. Since 1978, programs have been initiated to reduce or eliminate inputs of contaminants to the Great Lakes at locations such as the Niagara Frontier, the Detroit and St. Clair Rivers, and many Areas of Concern. These and other programs should be expedited so that the goals of virtual elimination and zero discharge can be realised.

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1. INTRODUCTION

The Great Lakes constitute the largest body of freshwater on earth. Ranked by surface area, Lake Superior is the second largest lake in the world. Lake Huron is the fifth largest, Lake Michigan the sixth largest, Lake Erie the thirteenth largest, and Lake Ontario the seventeenth largest (Beeton, 1984). The Great Lakes are one of the planet's great natural resources. In spite of the size of these waterbodies, they have been contaminated with toxic chemicals. The sources of the chemicals are agricultural, urban and industrial development. Some toxic chemicals are distributed throughout the entire Great Lakes ecosystem.

This report reviews the available information on concentrations of chemicals in the water and bottom sediments of the open Great Lakes and their connecting channels. Spatial and temporal trends are discussed where possible.

The introductory section consists of background information about toxic chemicals in the water and sediments of the Great Lakes. This includes the sources, pathways and fate of the chemicals in the system, a discussion of the main chemicals of concern, a history of Great Lakes contamination, and a description of water and sediment sampling and analysis. The overall organization of this report is by geographic location; that is, the data for each lake and connecting channel are presented in sequence from Lake Superior to the international section of the St. Lawrence River. For each body of water, the conditions of the water and then the sediments are discussed. The water sections are divided into two parts. The first reviews data on the aqueous phase and in total water and the second discusses concentrations in the suspended sediment phase. The sediment sections are also divided into two parts: surficial sediment concentrations and concentrations in sediment cores. In each of these four sections, concentrations of metals are discussed before those of organic contaminants. The main chemicals discussed are lead (Pb), mercury (Hg), cadmium (Cd), arsenic (As), DDT and metabolites, dieldrin, alpha-BHC, lindane, mirex, toxaphene, benzo(a)pyrene (B[a]P), dioxins and furans, HCB, HCBD and PCBs. There is a list of chemical abbreviations in Appendix 2. There are tables showing the concentrations of these chemicals in the water and sediments for each of the Great Lakes and the Niagara River. Representative core profiles for each of the Great Lakes show sediment concentration trends. Summaries of geographic patterns of contaminant distribution and concentration changes over time are given in the conclusion. There is a glossary in Appendix 3.

There is more information available on the contamination of the Great Lakes than for any other set of freshwater lakes in the world (Allan, 1988). This report is the most comprehensive document prepared to date on the concentrations of toxic contaminants in the water and sediments of all of the Great Lakes and their connecting channels. The sources used to prepare this literature review included journal articles, journal issues, reports, conference papers and proceedings, dissertations, monographs, and chapters. When possible, only primary published sources were used.

1.1 TOXIC CHEMICAL SOURCES, PATHWAYS AND FATE

The Great Lakes system flows from Lake Superior and Lake Michigan through the other Great Lakes and the St. Lawrence River to the Atlantic Ocean (Figure 1). The lakes are one unit and are connected by short narrows at Mackinac and by the short connecting channels of the St. Clair, Detroit and Niagara Rivers. These channels have extremely high discharges of approximately 6,000 m^3/sec, putting them on a scale with the world's largest rivers. The massive transfers of water into and out of Lakes Erie and Ontario are important for the fate of toxic chemicals in the lower Great Lakes. Less than 1% of the total volume of water in the system flows out annually through the St. Lawrence River. The residence times of the lower Great Lakes are strongly influenced by the flows of the connecting channels (Table 1).

The connecting channels, other tributaries and the atmosphere are major sources of many toxic chemicals to the lower Great Lakes (Strachan and Eisenreich, 1988). Canadian industry is concentrated along the shore of the St. Clair River. Detroit and Windsor are located on the shores of the Detroit River. Buffalo is located immediately upstream of the Niagara River. There has been major industrial development on the side of the Niagara River. Effluents from these cities and industries have introduced toxic chemicals into the connecting channels and thus to the downstream lakes (NRTC, 1984; UGLCCS, 1989). The connecting channels rapidly transfer chemicals discharged into them to the downstream lakes. For example, there is little or no long term removal of chemicals by burial in the bottom sediments of the Niagara River (Mudroch and Williams, 1989). Another important result of the high discharge rate of the channels is that chemical inputs are quickly diluted to extremely low concentrations in the water phase. But, because of the high discharge rates, these extremely low concentrations represent large loadings to the downstream lakes.

The two largest conurbations in the Great Lakes basin are the Gary-Chicago-Milwaukee area of southwestern Lake Michigan and the Hamilton-Toronto area of northwestern Lake Ontario. Contaminants are introduced to the lakes by urban runoff, via storm sewers and by many sewage treatment plants.

Today, non-point sources of chemical contamination, such as the atmosphere, agricultural runoff, and contaminated bottom sediments are recognized sources of contaminants to the lakes. Agricultural practices are sources of pesticides to tributaries of Lakes Michigan, Erie and Ontario, in particular. Because of their surface area, atmospheric deposition is a major source of chemicals to the Great Lakes (Strachan and Eisenreich, 1988).

The Great Lakes are frequently referred to as inland seas yet the processes such as sedimentation, photodegradation and bioaccumulation which control the fate of chemicals in these large lakes are similar to those in smaller lakes. Hydrophobic contaminants are found at the interfaces between water and other aquatic compartments such as inorganic and organic solids in the water column, or at surface microlayers between the water and the atmosphere. If they are associated with particulates, toxic chemicals become subject to limnological processes, such as sedimentation and accumulation in depositional basins. Burial in bottom sediments is a major process for aquatic ecosystem self-cleansing. In the deep lakes (Superior, Michigan, Huron and Ontario) toxic chemicals which have accumulated in bottom sediments are eventually buried beneath cleaner sediments and are removed from bioaccumulation pathways. The depth and size of the lakes also affects their biological productivity and thus the fate of the contaminants. Nutrient loads to the lakes also affect productivity. The relationship between nutrient status and the fate of toxic chemicals is not well established but it has been hypothesised that chemical concentrations at the top of aquatic food webs may be lower in nutrient rich lakes. The response of each lake to contamination is thus unique. The fate of toxic chemicals in the lakes is also governed by the physicochemical characteristics of the chemicals. These include solubility, volatility, hydrophobicity, lipophilicity, the degree of partitioning onto suspended solids, and the susceptibility to photo- and biodegradation. Once released to aquatic ecosystems, some chemicals rapidly disappear by degradation or volatilization to the atmosphere. Chemicals degradation can take place by a variety of chemical and biological processes including hydrolysis, photolysis, and bacterial or fungal dechlorination. Even short lived chemicals can be highly toxic while they are in the water column.

1.2 MAIN CHEMICALS OF CONCERN

Concern about the contamination of the Great Lakes have focused on persistent toxic chemicals. Toxic metals include lead, mercury, cadmium and arsenic, and persistent toxic organic chemicals include chlorinated pesticides such as DDT and mirex, chlorinated benzenes, chlorinated dioxins and furans, and PCBs.

In 1983, the IJC published a comprehensive inventory of chemical substances identified in the Great Lakes ecosystem. The 1986 working list of chemicals in the Great Lakes basin (IJC Comprehensive Track chemicals) was produced from this inventory. It contains 362 chemicals (IJC 1987b). Of these chemicals, 11 critical pollutants were chosen by the IJC for its Primary Track. Information used in deriving priority lists tends to include chemical stability leading to persistence in the environment, the quantities in use, the types of use, the tendency to accumulate in living organisms, and the biological effects associated with acute or chronic exposure (Hamilton *et al.*, 1987). In this report, all of the Primary Track chemicals are discussed as well as several of the Comprehensive Track chemicals.

In Canada, there are several sets of objectives and guidelines established for concentrations of toxic chemicals in water. Two of these are shown in Table 2. When developing and using guidelines for the protection of aquatic life, there should be complete information on the parameter of concern, including its form and fate in the aquatic environment, quantitative exposure/effect relationships, and its fate within organisms over a wide range of exposure concentrations. The relevant information base for a particular chemical is rarely complete. In general, water quality guidelines used in

Canada are based on unfiltered water samples (CCREM, 1987). The first set of objectives shown are the 1978 Great Lakes Water Quality Agreement specific objectives. These were amended by the 1987 Protocol. Although the Protocol stated that the discharge of toxic substances in toxic amounts should be prohibited and the discharge of any or all persistent toxic substances should be virtually eliminated (IJC 1988), the specific objectives listed in the revised 1978 Agreement were adopted in 1987 as interim objectives for persistent toxic substances. The second set of guidelines has been proposed by the Canadian Council for Resource and Environment Ministers. In 1984, CCREM approved a recommendation from the Task Force on Water Quality Guidelines that Canadian water quality guidelines be harmonized (CCREM, 1987). The guidelines are presented here for comparison with the IJC objectives. The introduction to the Task Force report states that the guidelines should not be regarded as blanket values for national water quality and that variations in environmental conditions across Canada will affect water quality in different ways so that many of the guidelines will need to be modified according to local conditions (CCREM, 1987).

Criteria and standards are still being developed for sediments, however, the role of sediments as a source of chemical contaminants to the aquatic environment is poorly understood. The existing criteria for open lake disposal of dredged materials were developed as a guide to determining appropriate disposal techniques for dredged materials, not for ambient water quality evaluation and/or ecosystem risk assessment. They are as follows: mercury 0.3 ppm, lead 50 ppm, cadmium 1.5 ppm, arsenic 8 ppm and PCBs 0.05 ppm. For other organic contaminants, the guideline is below the minimum detection level using the best available technology.

In this report concentrations are reported in ppm, ppb, ppt or ppq. Examples of the wet and dry weight concentrations these represent are given in Table 3.

1.3 HISTORY OF CONTAMINATION

In the early 1960s, pesticides, such as DDT, were detected in the Great Lakes. This was followed by the detection of other organochlorine pesticides and industrial chemicals, such as PCBs (Williams, 1975; D'Itri, 1988). In 1968, mercury (Hg) was detected in high concentrations in sediments from

Lakes Ontario and Huron (Thomas, 1972; 1973). Concurrently, high concentrations of mercury were discovered in Lake St. Clair fish (Fimreite *et al.*, 1971) at levels which resulted in a ban on commercial fishing in the lake in 1970. The source of mercury to Lake St. Clair was upstream chlor-alkali plants on the St. Clair River. In 1971, the Michigan Public Health Department issued a consumption advisory because of PCBs in lake trout and salmon in Lake Michigan. Soon after, in 1974, mirex was discovered in fish in the Bay of Quinte, Lake Ontario. In late 1979, chlorinated dioxins were detected in herring gull eggs from colonies in Saginaw Bay, Michigan. In 1982, toxaphene was first detected in fish from Lake Superior. Subsequent sampling showed that most of these chemicals were present throughout the Great Lakes system. Also, analyses of Great Lakes media for metals, such as lead and cadmium, showed that these were also ubiquitous contaminants. Thus, the scientific and public awareness of the level of toxic chemical pollution of the Great Lakes developed over approximately 25 years. The period of greatest public concern was around 1980 and was related to the discovery of 2, 3, 7, 8-tetrachloro-dibenzo-(p)-dioxin, in herring gull eggs. Another major event occurred in 1985 when there was a perchloroethylene spill into the St. Clair River.

Chemical analyses of radiodated sediment cores showed that contamination of the Great Lakes began only after World War II, concurrently with the expansion in urban and industrial development. PAHs were detected in lake sediments deposited at the turn of the century. Some chlorinated organics such as PCBs and chlorinated benzenes (CBs) were produced before the war. However, peak inputs of these chemicals and chlorinated pesticides took place much later in the 1950s, 1960s and early 1970s. During the 1970s, it became apparent that bottom sediments were contaminated with organochlorine pesticides and PCBs.

1.4 SAMPLING AND ANALYSIS

The chemicals discussed in this report are those traditionally analyzed for in most media. However, recent attempts to calculate mass balances for the Great Lakes have shown that the data bases are quite inadequate, with the possible exception of PCBs (Strachan and Eisenreich, 1988). Since about 1979, concentrations of hydrophobic chemicals have been measured in suspended particulates. Previously, water column concentrations and trends had been assessed by analysis of suspended solids, for example, in the connecting channels such as the Niagara River. However, at the low suspended solids concentrations common in the Great Lakes system, even the most hydrophobic organic chemicals are primarily in the dissolved phase. At that time, reliable quantitative data for toxic contaminants in water were scarce. Nearly all historical results were below the existing detection limits. Concentrations in water are often an order of magnitude or more, less than the minimum detection levels in routine sample volumes of 1 to 2 litres. Only since 1980 has it been possible to determine concentrations of some of these chemicals in water in the open lakes and connecting channels. Large volumes of water (200 litres) are now extracted to detect concentrations in the low ppt and ppq ranges. Measurements of ambient concentrations in water are complex and have become semi-routine only since 1983. Because of these complex, time consuming and costly procedures for sample collection, preparation and analyses, few measurements for toxic organic chemicals have been made in all parts of the Great Lakes. The values for whole water, and especially for the dissolved phase are highly variable in space and time and must still be viewed with caution as they are often near limits of analytical detection. Despite these problems, it is important to measure concentrations in water because such data can provide information on:

(1) The relationship of chemical concentrations in water to those in fish;
(2) The several orders of magnitude higher concentrations of these chemicals in bottom sediments in cause-effect linkages;
(3) The burial of chemicals in lake sediments as a self-cleansing process; and
(4) Model chemical fate or concentrations for mass balances so as to determine major sources of toxic chemicals and prioritize control actions.

Concentrations of chemicals in waters and suspended solids can change rapidly depending on sources, bottom sediment resuspension, internal productivity, currents and many other seasonal and limnological processes. In nearshore areas and in the connecting channels, concentrations of chemicals in water and suspended particulates can vary considerably over short periods of time.

Much of the historical data on dissolved metals in water from the open lakes have recently been questioned. Metals are ubiquitous and found in sampling platforms such as boats, and in dust from laboratories. This suggests that samples could have been contaminated, particularly with lead and cadmium. The bottom sediment and most suspended solids chemical data which follow are reliable. Sectioned, radiodated sediment cores have shown long term trends in chemical inputs to the lakes. These trends can be extended to pre-industrial and even pre-colonial periods. Bearing in mind these problems, two types of chemicals are discussed in this report:

1) Toxic chemicals for which there is a reasonably extensive data base. They include lead, mercury, cadmium, and arsenic, DDT and metabolites, dieldrin, BHCs, HCB, dioxins, and PCBs .

2) Toxic chemicals for which there is a geographically restricted data base. Such chemicals include: chlorobenzenes (e.g., Lake Ontario); toxaphene (e.g., Lake Superior); octachlorostyrene (OCS) (e.g., Lake St. Clair); mirex (e.g., St. Lawrence River); chlorinated volatile organics (e.g., the lower Great Lakes and connecting channels); and PAHs (e.g., western Lake Erie).

2. TOXIC CHEMICALS IN WATER, SUSPENDED SOLIDS, AND BOTTOM SEDIMENTS OF THE GREAT LAKES AND THEIR CONNECTING CHANNELS

There have been several comprehensive studies of toxic chemicals in different regions of the Great Lakes. These include:

Allan *et al.* (1983), Niagara River Toxics Committee Report (NRTC, 1984), Chau *et al.* (1985), Lawrence (1986), Canada - Ontario St. Clair River Pollution Investigation report (1986), and the Upper Great Lakes Connecting Channels Study (UGLCCS, 1989). Information on the concentrations and fate of toxic chemicals in the connecting channels (the St. Clair, Detroit and Niagara Rivers) and the fate of these chemicals downstream in Lakes St. Clair, Erie and Ontario, has added significantly to the rapidly expanded data base.

There have also been several studies which covered all or most of the lakes. Between 1968 and 1975, bottom sediment surveys of some metals and organic chemicals were conducted on each of the lakes and composite geochemical maps were produced. These were extremely valuable for inter-lake comparisons. The interpretation of the distributions must, however, be related specifically to the years of sample collection. This type of survey has not been repeated. During the 1980s, Rossman (1982, 1983, 1984, 1986, 1988) studied metals in the waters of each of the Great Lakes. He attempted to determine temporal trends and made inter-lake comparisons. In 1981, Sonzogni and Simmons presented typical concentration ranges for lakes. Mudroch *et al.* (1988) summarized sediment concentrations of some metals and PCBs in each lake. Strachan and Eisenreich (1988) recently attempted to provide representative values for toxic chemical concentrations in Great Lakes water and sediments. They assessed the best available values in early 1986 when they attempted to calculate mass balances for several toxic chemicals in each lake. Concurrently, Stevens and Neilson (in press) collected large volume (37 to 55.5 L) surface water samples from Lakes Superior, Huron, Erie and Ontario and examined them for toxic organic chemicals (Stevens and Neilson, in press). The results of these studies are in the summary tables for each of the Great Lakes and the Niagara River.

2.1 LAKE SUPERIOR

Lake Superior has the largest surface area of any lake in the world. By volume, it represents half of the water stored in all the Great Lakes and is the second largest lake in the world, after Lake Baikal in Siberia. The main tributaries to Lake Superior are the Nipigon, St. Louis, Pigeon, Pic, White, Michipicoten and Kaministiquia Rivers. The lake discharges via the St. Marys River. It is primarily surrounded by the forested, Precambrian terrain of the Canadian Shield.

Chemical mass balance calculations have shown that the atmosphere is a major source of contaminants such as PCBs, DDT, B(a)P and lead, to Lake Superior (Young *et al.*, 1987). There are several reasons for this. Compared with the other Great Lakes, Lake Superior has less agriculture, population and industrialization. This results in lower overall contamination from these sources. Also, the surface of the lake is about 40% of its drainage basin; the precipitation over the lake accounts for more than 50% of the total water input; and the lake has a long residence time combined with rapid circulation and low sedimentation (Chan, 1984).

2.1.1 Water and Suspended Solids

The historical concentrations of toxic metals and organic chemicals in the waters of Lake Superior are shown in Table 4. As discussed earlier, much of the historical data, especially on metals, has recently been questioned. Rossmann (1986) compared his 1983 data on concentrations of metals in the dissolved, particulate and total water phases to earlier data for Lake Superior. The results for lead, mercury, cadmium and arsenic are discussed below. He concluded that the historical data could only be used to determine trends for total mercury and total arsenic. The decline in concentrations of mean total arsenic was 28 ppt/year based on data from 1973-1983 (Rossmann, 1986). His metal results were all below the IJC Great Lakes Water Quality objectives. Rossmann and Barres (1988) compared the 1983 results for Lake Superior with similar studies on the other Great Lakes done between 1980 and 1985. Generally, the mean concentrations of lead, mercury, cadmium and arsenic in dissolved and total water samples from Lake Superior were significantly (0.05 level of significance) less or not significantly different from concentrations in the other Great Lakes. However, the concentration of dissolved arsenic was significantly higher in Lake Superior than Lake Huron. High levels of lead, mercury and cadmium have been reported in the harbours and bays of Lake Superior in the 1980s (Simpson, 1987; Kirby, 1986; Glass *et al.*, 1988).

There have been several studies of toxic organic chemicals in Lake Superior. The results are shown in Table 4. The most recent results show (Stevens and Neilson, in press) that concentrations of all detectable organic contaminants in 1986 were slightly higher in the north than the south of the lake, especially in the vicinity of Nipigon Bay, Jackfish Bay, Peninsula Harbour and Michipicoten Bay. Concentrations of chlorobenzenes, dieldrin, and PCBs were not significantly different from those in Lake Huron and they were consistently ranked lower than those in Lake Ontario. The mean concentrations of some of the organic contaminants studied by Stevens and Neilson are given in Table 4.

The most frequently detected persistent, toxic, chlorinated organic chemical in most of the lakes and connected channels is total PCBs. There are considerable variations in PCB concentrations in lake waters due to ice cover, ice melt, spring overturn and evaporation (Capel and Eisenreich, 1985). Capel and Eisenreich (1985) reported mean total PCB concentrations at the centre of Lake Superior as 1.30 ppt (1978), 3.8 ppt (1979), and 0.9 ppt (1980). Baker *et al.* (1985) reported mean concentrations of 0.95 ppt (1978), 3.3 ppt (1979), 0.75 ppt (1980), and 0.63 ppt (1983). Their overall conclusion was that lake-wide PCB concentrations in water are probably decreasing. The results in Table 4 for whole water lead to a similar conclusion. Eisenreich (1987) estimated the decrease from 1978 to 1983 to be 54%. The residence time for PCBs in Lake Superior waters was estimated as 2 to 6 years, compared with to the hydraulic residence time of 170 to 180 years. On this basis, it was predicted that concentrations of total PCBs would decline in Lake Superior water to about 0.2 ppt by 1990 (Eisenreich, 1987). The latest measurements in 1986 were 0.3 ppt in whole water (Stevens and Neilson, in press) and 0.55 +/- 0.37 ppt in the dissolved phase (Baker and Eisenreich, 1989). The highest values in 1986 were 0.56 and 0.58 ppt in Duluth - Superior Harbour and South of the Apostle Islands respectively. The higher values reported by Chan (1984) for 1983 (Table 4) may be the result of analytical artifacts.

The concentrations of toxic chemicals in particulates in Lake Superior are given in Table 4. The benthic nepheloid layer has been described by Baker *et al.* (1985) and Baker and Eisenreich (1989). Rossmann (1986) reported that in 1983, particulate arsenic concentrations were significantly higher in the eastern region than in the central region. The 1977 data discussed above cannot be compared with the 1983 data because of sample contaminations and the use of different analytical procedures. Rossmann and Barres (1988) compared the 1983 results of metal particulate concentrations for Lake Superior with similar studies on the other Great Lakes done between 1980 and 1985. Generally, the mean concentrations of lead, mercury, cadmium and arsenic in particulates of Lake Superior were significantly less, or not significantly different from concentrations in the other Great Lakes. The exception was the concentration of particulate cadmium which was significantly higher in Lake Superior than in Lake Michigan.

There are limited data on toxic organic chemicals in suspended solids, other than those for PCBs. Most concentrations were measured in whole water samples (Table 4). Baker *et al.* (1985) reported DDE concentrations in suspended solids from the nepheloid layer of western Lake Superior in 1983 as being from 0.005 to 0.024 ppt. They also found that the concentrations of particulate-associated PCBs in the benthic nepheloid layer were not that different from those in the epilimnion. In 1980, the range of PCB concentrations in suspended solids was 30 to 2,770 ppb (ng/g) (Capel and Eisenreich, 1985). Capel and Eisenreich pointed out that the fraction associated with particulates versus the dissolved phase changed with time and with depth. By 1986, the particulate-associated PCB concentration had dropped dramatically to 33 +/- 16 ppb (ng/g) (Baker and Eisenreich, 1989). Concentrations of some PCBs and PAHs in Lake Superior were greater in suspended solids collected by sediment traps than when collected by centrifugation (Baker and Eisenreich, 1988). This was thought to be related to biological processes. They found that the flux rates of PCBs to the bottom waters of Lake Superior were up to two orders of magnitude higher than the net accumulation rates of PCBs in the bottom sediments, implying high benthic organism recycling rates. Particulate concentrations of total PCBs could thus be higher than those found in surficial sediments. When Lake

Superior was stratified, the fraction of total PCBs associated with particulate phases at all depths was around 13 - 14% (Baker *et al.*, 1985). The highest concentrations of particulate PCBs were in the eastern basin of the lake in 1980 (Capel and Eisenreich, 1985). In 1986, individual particulate PAH concentrations ranged from less than one to a few hundred ppb (Baker and Eisenreich, 1989).

2.1.2 Bottom Sediments

The most extensive sampling of bottom sediments of Lake Superior was conducted in 1973 as part of multi-year program to map chemical distributions in the surficial bottom sediments of all five Great Lakes. Although distribution maps for different chemicals were published in separate papers, the report by Thomas and Mudroch (1979) contained nearly all of the distribution maps for metals and organic chemicals for all five lakes. This survey has not been repeated. The maps represent the distribution of chemicals in the bottom sediments only for the period when the samples were collected. The top 3 cm of sediment were used in the analysis to produce the maps. This depth can represent different numbers of years of sediment accumulation depending on the lake and location in the lake. The present day surficial concentrations and distributions of toxic metals and organic chemicals will be probably quite different from those represented by samples taken in the late 1960s and early 1970s. Two maps are included in this report. The first is for mercury which may be the most serious metal contaminant of the lakes (Figure 2). The second is for total PCBs, because this is the most extensively studied toxic organic chemical in the Great Lakes (Figure 3).

In Lake Superior, the concentrations and distributions of metals were principally related to the geology of the area surrounding the lake. Thomas and Mudroch (1979) proposed that copper was an exception and that concentrations of this metal were related to inputs from mines. Surface sediment concentrations of lead were usually less than 100 ppm and less than 4 ppm for cadmium (Table 5). Information on the arsenic content of Lake Superior bottom sediments showed that the concentrations in the Thunder Bay basin were 2.0 ppm (n = 15) with a range of 0.5 to 8.0 ppm in 1973 (Traversy *et al.*, 1975). In general, information about arsenic concentrations in Great Lakes sediments is scarce (Mudroch *et al.*, 1985).

The distribution of several organochlorines in bottom sediments was determined in 1973 (Frank *et al.*, 1980) (Table 5). The mean values (n = 406) for total PCBs and p,p'-DDE were 3.3 ppb and 0.71 ppb, respectively, for all basins. Eisenreich *et al.* (1980) sampled Lake Superior bottom sediments in 1977 and 1978. Whereas Frank *et al.* (1980) analyzed the top 3 cm, concentrations reported in Eisenreich *et al.* (1980) are for the top 0.5 cm only. Eisenreich and Baker (1989) reported that the mean total PCB concentration in 1986 (8.6 ppb) was significantly lower than that in 1978 (74 ppb). This reflects lower PCB burdens in the water column. The mean HCB concentration of 0.2 ppb in surficial sediments in 1980 was at least an order of magnitude lower than that in Lakes Huron, Erie and Ontario (Oliver and Nicol, 1982). Frank *et al.* (1980) did not detect mirex in any of 80 samples collected in 1973, at a minimum detection limit of 0.3 ppb. PAH concentrations in sediments are about ten times lower than in the other Great Lakes, reflecting both its remote location and that the atmosphere is the primary source (Baker and Eisenreich, 1989).

Historical trends in loadings of heavy metals to Lake Superior have been investigated by collection, sectioning, age dating and analysis of lake bottom sediment cores. Kemp *et al.* (1978) calculated sediment enrichment factors for several metals in Lake Superior. The mean values for lead, mercury, cadmium and arsenic were 4.6, 1.8, 2.9 (n = 6) and 0.7 (n = 1), respectively. The sediment enrichment value is the ratio of the surficial sediment concentration to the historical, pre-settlement concentration below the Ambrosia horizon. Cores analyzed by Rossmann (1986) show that concentrations of lead have increased in the most recent sections of sediment cores (Figure 4). Because most lead introduced to Lake Superior comes from the atmosphere, it is likely that concentrations in the surface sediments will now decrease as they have, for example, in Lake Ontario (Rossmann, 1986). Anthropogenic enrichment of lead in Lake Superior has been less than that in the other Great Lakes (Hodson *et al.*, 1984). Concentrations of mercury reached peak values at a depth of 3 cm and decreased to the surface (Figure 4).

The distribution of PCBs in sediment cores from nine sites in Lake Superior was described by Eisenreich (1988). The top 1 cm of sediment represented approximately 10 years. At all sites, the concentrations of PCBs began to increase at a depth corresponding to the late 1940s. Peak concentrations varied at each of the sites but were either at the surface or at a depth of 1 cm, representing the early 1970s. In general, Lake Superior has the lowest sedimentation rate of all of the Great Lakes (Thomas and Frank, 1983). In seven of the nine cores, the top 0.25 cm had concentrations of total PCB that were 20 to 100% less than the next 0.25 cm section. This could be evidence of a recent decrease in the sedimentation of PCBs. The mean value for the whole lake in the top 0.5 cm was 53 ppb total PCBs. Charles and Hites (1987) determined the average PCB concentration as a function of time in three sediment cores from Lake Superior (Figure 4). The distribution shows a slow increase from around 1943 to 1955; a rapid rise from 1955 to a peak value of 110 ppb in 1972-73; followed by a decline to 75 ppb by 1975. This decline should continue as North American bans and restrictions on PCBs take greater effect. Most of the PCB input to Lake Superior is from the atmosphere (Strachan and Eisenreich, 1987).

The historical distribution of some PAHs in Lake Superior sediment cores show that inputs of these chemicals to the lake began after the turn of the century. The highest B[a]P concentration in a Lake Superior core was around 30 ppb at a depth of 0.25 cm (Gschwend and Hites, 1981). Although B[a]P concentrations in Lake Superior bottom sediments more than tripled between 1900 and 1980, concentrations are still an order of magnitude lower than in the lower Great Lakes because the region around Lake Superior is far less industrialized (Eadie, 1984). In Lake George, which is part of the St. Marys River connecting channel between Lake Superior and Lake Huron, B[a]P concentrations in sediment cores show recent declines (Figure 4).

2.2 LAKE MICHIGAN

Lake Michigan is the only Great Lake to lie completely within the U.S. It is the sixth largest lake in the world both by area and volume. Downstream, it is connected to Lake Huron by the Straits of Mackinac. The lake is essentially two basins, a southern basin with depths up to 170 m and a northern basin with depths up to 280 m.

The contamination of Lake Michigan by organochlorine chemicals began at the same time as for the other Great Lakes, in the 1920s and 1930s, but increased rapidly after World War II. Contamination of the southern end of the lake has been more severe than the northern end. One of its main tributaries is Fox River which empties into Green Bay. The bay is about 8% of the surface area of the lake but it has about one third of the lake's watershed (Harris *et al.*, 1987). There has been concern about water quality in Green Bay since the 1920s.

2.2.1 Water and Suspended Solids

Published data on chemical concentrations in Lake Michigan water are shown in Table 6. Historical data on total lead concentrations in Lake Michigan waters were reviewed by Rossmann (1984). The values for both total and dissolved lead as determined by Rossmann in 1981 are much less than many of the historical levels measured in the 1960s and 1970s because of sample contamination problems. Rossmann's mean values of 260 ppt total lead and 150 ppt of dissolved lead (n = 11) are considered the most accurate. Earlier measurements of total lead had ranged up to 170 ppb with a mean of 18 ppb (n = 30) in 1976 (Wisconsin Electric Power Company and Wisconsin Michigan Power Company, 1977, as cited in Rossmann, 1984). Reported historical mean mercury values were as high as 4.3 ppb (Rossmann, 1984) but these earlier values are now considered to be invalid. All of the cadmium measured by Rossmann in 1981 at 11 sites was in the dissolved phase. Earlier mean cadmium values as high as 2,800 ppt (n = 42) in 1974 are now considered to be erroneous. Owen and Meyers (1984) reported total cadmium concentrations in the mid-lake subsurface in the late 1970s were 70 ppt and nearshore subsurface as 80 ppt. In southern Lake Michigan, the mean concentration of total cadmium was 26.6 ppt with a range of 12.0 to 45.6 ppt (Lum, 1987). These values are similar to Rossmann's (Table 6). Rossmann considered historic arsenic concentrations to be valid for comparison with recent results. Values of just over 1,000 to 2,000 ppt were measured in the mid to late 1970s and compared to Rossmann's whole water mean value in 1981 of 790 ppt. Much higher values for mean total arsenic were reported prior to 1970 (up to 40 ppb in 1969) but these were almost certainly analytical artifacts.

There is little published information available on organochlorines in Lake Michigan water (Table 6). From 1968 to 1970, total DDT values were reported as 3 to 151 ppt (Sonzogni and Simmons, 1981). Open water samples collected in 1968 and analyzed for dieldrin by three independent laboratories contained a mean value for dieldrin of 1.0 ppt. In the late 1970s, dieldrin was undetected at 0.1 ppt using better detection methods (Sonzogni and Simmons, 1981). Analyses of nearshore samples for toxaphene from 1972 to 1976 failed to detect the chemical at the 1.0 ppb level. The data on PCB concentrations in Lake Michigan waters are more extensive than those on other toxic organics because this chemical is one of the main contaminants. Rare measurements from the early 1970s indicated that total PCB concentrations in water may have been from 30 to 40 ppt (Swackhammer and Armstrong, 1987). These were probably a result of analytical problems which were not resolved until the early 1980s . Rodgers and Swain (1983) reported water column PCB concentrations of 3 to 9 ppt for 1976. In 1980, Swackhammer and Armstrong (1987) reported an open lake average of 1.2 ppt total PCB, lower than the nearshore average of 3.2 ppt. They found little variability in PCB concentration with lake depth.

Data on concentrations of toxic chemicals in Lake Michigan particulates are shown in Table 6. Rossmann's results (1984) indicated that in the water column, the percentage of cadmium and arsenic present in the dissolved and total fractions were such that the particulate fraction did not make a significant contribution to total concentrations.

2.2.2 Bottom Sediments

Concentrations of toxic chemicals are significantly higher in the depositional basins. Not all of the metals are anthropogenic, but all of the toxic organic chemicals are. Data on concentrations of toxic chemicals in bottom sediments are shown in Table 7. The most extensive surficial sediment survey of Lake Michigan was done in 1975. The distributions of lead, mercury and arsenic were similar. Based on 1973 samples, concentrations of cadmium ranged from 0.09 to 1.93 ppm (Cline and Chambers, 1977). In northeastern Lake Michigan, the mean value was 0.47 ppm and in Green Bay in northwestern Lake Michigan it was 1.3 ppm (n = 5) (Lum, 1987). Only very small areas of the lake exceeded 300 ppb mercury (Cahill and Shrimp, 1984). The highest concentrations of arsenic were in Green Bay.

In 1963, sampling had indicated that some sediments in Lake Michigan had up to 20 ppb of DDE (Hickey *et al.*, 1966). In 1975, mean total DDT in surficial lake bottom sediments was 11.9 ppb (Table 7). The mean for the depositional basins was 24.4 ppb (n = 92) (Frank *et al.*, 1981a). The corresponding mean concentrations of p,p'-DDT, o,p'-DDT, p,p'-TDE and p,p'-DDE were 2.9 ppb and 5.4 ppb, 0.37 ppb and 0.73 ppb, 3.25 ppb and 7.65 ppb, and 5.43 ppb and 10.58 ppb, respectively. The distribution of total DDT was similar to that of the heavy metals. Persistent, hydrophobic organic chemicals are associated with the fine particulate phases which accumulate in the major depositional basins. Most samples had dieldrin concentrations of less than 1.1 ppb. Prior to 1977, dieldrin levels in sediments from southern Lake Michigan of less than 0.5 to 10.4 ppb were reported (Sonzogni and Simmons, 1981). Lake Michigan has high sediment concentrations of PAHs (Table 7). In 1979 to 1980, the mean concentration of B[a]P in Lake Michigan sediments from the depositional basins and non-depositional areas was 462 and 62 ppb respectively (Eadie *et al.*, 1983). Two major sources of PCBs in the south west part of the lake drainage basin at Milwaukee and at Waukegan are easily discernible from the concentrations in surficial sediments (Figure 3). The mean PCB concentration in the depositional basins of the lake in 1975 was 17.3 ppb (Frank *et al.*, 1981a). Lake Michigan contains some of the areas most heavily contaminated with PCBs. They include Waukegan Harbour (500,000 ppm), North Ditch (250,000 ppm), and Milwaukee Harbour (6.4 ppm) (Simmons, 1984).

The distribution of chemicals in sediment cores from Lake Michigan suggests that inputs have decreased. Lake Michigan has low sedimentation rates which range from 0.1 to 4 mm/year (Cahill and Shrimp, 1984). Concentrations of metals in sediment cores from Lake Michigan show that lead, cadmium and other metal contamination started in the 1890s in the southern part of the lake and in about 1920 further north (Christensen and Goetz, 1987). The major increase in lead (Figure 5) began in about 1930 and rose rapidly to a peak between 1960 and 1970. Lead concentrations in the immediate surface decreased to levels similar to those between 1950 and 1960 (Goldberg *et al.*, 1981). This agrees with Christensen and Goetz (1987) who calculated that the period of maximum lead inputs was 1954-1969 and that present inputs have decreased by 35-45% from these maxima. Maximum cadmium pollution occurred between 1939 and 1954 and current levels are 35 to 45% less than these maxima. Goldberg *et al.* (1981)

determined the period of maximum cadmium input to be in the late 1960s. Measurable amounts of PCBs were detected in a core at 3-4 cm depth (Swackhammer and Armstrong, 1986). This corresponds to a period from 1920 to 1950 and indicates that inputs to the lake began soon after commercial sales of PCBs started in the U.S. in 1929. The largest loadings to the sediments took place between 1960 and the early 1970s. Sediment cores have also shown that the initial inputs of dioxins and furans to Lake Michigan began around 1940 (Czuczwa and Hites, 1986).

2.3 LAKE HURON

The surface area of Lake Huron is 59,600 km^2. By volume, it is the seventh largest lake in the world and the third largest Great Lake at 3,540 km^3. Its drainage basin is 134,100 km^2. The maximum depth is 229 m and water retention time is 22 years. The major inflows are the Straits of Mackinac and the St. Marys River, followed by the Mississagi, Saginaw, French and Spanish Rivers. It discharges to the St. Clair River. Manitoulin Island and the Bruce Peninsula divide the body of the lake from the North Channel and Georgian Bay, respectively. The lake is used for both commercial and recreational fishing. In 1978, the catchment area was mainly natural landscape. Toxic chemical inputs come from municipal point sources, combined sewer overflows, rural and urban nonpoint sources, leachates from municipal and hazardous waste landfill disposal sites and from the atmosphere. Problems related to industrial sources are most apparent in industrialized harbours and embayments such as Saginaw Bay. Saginaw Bay extends 82 km from the main body of the lake. The city of Saginaw is at the head of the bay and on the Saginaw River. It was historically a lumbering centre and now supports agriculture and diversified manufacturing. The bay is used for commercial fishing and summer recreation. The other large bay on Lake Huron is Georgian Bay, which is 190 km long and 80 km wide. The surrounding area is mainly forested although there is some agriculture in the south. There are several important commercial shipping ports located on Georgian Bay.

2.3.1 Water and Suspended Solids

Data on concentrations of contaminants in Lake Huron water are summarised in Table 8. Rossmann (1983) reviewed toxic metal concentrations in Lake Huron. He compared his 1980 lead data to those from previous studies and concluded that there was a downward trend in dissolved lead concentrations. Data on mercury, cadmium and arsenic prior to 1980 could not be used to establish trends. In 1980, concentrations of dissolved cadmium in Lake Huron were significantly lower than those of Lakes Erie and Michigan and there was no significant difference between the Lake Huron levels and those of Lakes Superior and Ontario (Rossmann and Barres, 1988). Total cadmium levels were significantly less than in Lakes Erie and Ontario. In Saginaw Bay, very limited data from 1985 suggest that lead and cadmium concentrations in the water column were at or below levels measured in 1976-1978 (IJC, 1987a). The 1980 dissolved arsenic levels in Lake Huron were significantly lower than those of Lakes Michigan, Ontario and Superior but not significantly different from levels in Lake Erie (Rossmann and Barres, 1988). The median concentration of total arsenic in Lake Huron was significantly lower than that of Lake Michigan but not significantly different from that of Lake Erie.

Concentrations of toxic organic chemicals in Lake Huron water are summarised in Table 8. In 1974 and 1975, concentrations of DDT in Saginaw Bay exceeded the GLWQA objective of 3.0 ppt. However, all subsequent reported concentrations were substantially below the objective level (Kreis and Rice, 1985). In a review of historical data, Kreis and Rice (1985) found that all concentrations for the sum of dieldrin-aldrin were below the GLWQA objective concentration of 1.0 ppt. A single concentration of 0.5 ppt had been reported for Lake Huron in 1975, considerably below the GLWQA objective of 10.0 ppt. The IJC (1981) reported that toxaphene levels in water from Lake Superior and Lake Huron ranged from 0.1 to 1.0 ppt. In Lake Huron the highest PCB concentration (191 ppt) was observed in 1979 at Harbour Beach, Michigan (Anderson *et al.*, 1982). The highest PCB concentrations measured in 1980 were in the North Channel (1.56 ppt) and Georgian Bay (1.17 ppt)(Filkins and Smith, 1982).

In 1980, a survey of toxic metal concentrations in suspended solids was conducted in Lake Huron (Rossmann, 1982) (Table 8). Particulate lead levels were somewhat lower in the southern part of the lake and in Georgian Bay than in the rest of the lake. The highest particulate cadmium concentrations were found in Georgian Bay and the North Channel. The particulate cadmium level in Lake Huron was significantly less than in Lake Ontario but not significantly different from Lakes Superior and Michigan (Rossmann and Barres, 1988). Rossmann (1982) concluded that 100% of the total cadmium and 62% of the total mercury were associated with particulate matter. In 1980, particulate arsenic concentrations were highest in southern Lake Huron and in Georgian Bay. Only 3% of the arsenic was in the particulate form.

Most data on toxic organic chemicals in Lake Huron is based on whole water analyses. Some data on particulate concentrations for some toxic organic chemicals are shown in Table 8. In 1974, of nine streams sampled around Lake Huron, only one showed unusually high concentrations of total DDT in suspended solids (Frank *et al.*, 1981b). That was the Beaver River on the south shore of Georgian Bay with a level of 1.3 ppm. Total DDT in the remaining streams ranged from less than 0.5 to 44 ppb. In 1974 and 1975, the mean levels of total DDT and dieldrin and PCBs were 7.2 and 8.7 ppb, 0.4 ppb and 0.3 ppb, and 36 and 63 ppb. Mirex was not detected.

2.3.2 Bottom Sediments

Data on toxic chemical concentrations in bottom sediments are shown in Table 9. In the studies done by both Thomas and Robbins, most lead concentrations in surficial sediments were less than 100 ppm. Mudroch *et al.*'s (1988) review described surface sediment in depositional basins as having up to 151 ppm lead with surface sediments in embayments to be somewhat higher at up to 230 ppm. Fitchko and Hutchinson (1975) found high lead levels near Parry Sound and in the sediments of the Cheboygan River. Increased concentrations of mercury near the Bruce Peninsula may be due to sphalaerite mineralization (Fitchko and Hutchinson, 1975). Mudroch *et al.* (1988) found surface sediment concentrations of mercury in depositional basins to be up to 0.805 ppm and in embayments to be up to 9.5 ppm. Most areas of Lake Huron have cadmium concentrations of less than 4 ppm, although a few discrete areas in Georgian Bay have concentrations greater than 6 ppm (Thomas, 1981). An anthropogenic source in the southern part of the lake was suspected but no trends were observed in Georgian Bay. Mudroch *et al.* (1988) found a range of <0.3-4.6 ppm cadmium in embayments.

The highest organic chemical residues in surficial sediments from Lake Huron were in Saginaw Bay. Some other nearshore localities also have higher concentrations. In the open lake, the highest concentrations of toxic organic chemicals are in the depositional basins. This is because of the previously described relationship between hydrophobic organic chemicals and fine-grained sediments. Data on toxic organic chemical concentrations in bottom sediments are shown in Table 9. In 1969, Frank *et al.* (1979b) found levels of DDT were higher in depositional (18.4 ppb) rather than non-depositional zones (3.8 ppb). Of the six basins in Lake Huron, the highest concentrations of DDT were in the Goderich Basin (31.3 ppb). Concentrations of the parent compound (DDT) were the highest, followed by DDE and TDE. Although the inputs were primarily diffuse, Saginaw Bay, Wasaga Beach and the central part of eastern Georgian Bay were identified as point sources.

In 1969, dieldrin was identified in only 5.7% of the surface sediment samples. Concentrations were at or below 1.3 ppb (Frank *et al.*, 1979b). Samples containing dieldrin came from the Goderich and Mackinac Basins and in the non-depositional zone near Saginaw Bay. Dieldrin was identified in 30% of the sediments from Georgian Bay in 1973 and 15% of those from the North Channel (Frank *et al.*, 1979b). Kreis and Rice (1985) reported that mean dieldrin concentrations were high in Georgian Bay, particularly in Lions Trough and the nearshore zone at Owen Sound. Some samples from Saginaw Bay also had high concentrations, whereas the main lake and the North Channel had lower concentrations. Mirex was not detected by Frank *et al.* (1979b) in sediments collected in 1969 nor by Oliver and Bourbonniere (1985) in 1980. In 1969, unlike DDT, the PCB residues (11 ppb) in the non-depositional zones of Lake Huron were similar to the levels observed in the depositional basins (15 ppb) (Frank *et al.*, 1979b). Saginaw Basin contained the highest mean residue (33 ppb) and Alpena Basin the lowest (9 ppb) (Figure 3). The mean concentration in Georgian Bay was 13 ppb while in the North Channel, it was 8 ppb. In Georgian Bay, substantial loadings of PCBs probably came from the northeast shore (Frank *et al.*, 1979b). In the review by Mudroch *et al.* (1985), surface concentrations of PCBs ranged from 10-20 ppb in the open lake. In the embayments, they ranged from less than the minimum detection level to a maximum of 490 ppb. Rice and Evans (1984) reported that there were no data on toxaphene concentrations in bottom sediments from Lake Huron. In 1981, Czuczwa and Hites (1984) found that PCDDs and PCDFs were ubiquitous in 1 cm surface sediment samples and concentrations were higher closer to urban centres than in the open lake. There was a predominance of OCDD and HpCDF. They concluded that the source of the dioxins and furans was probably the municipal and/or industrial combustion of wastes containing chlorinated organic products. Average OCDD in the surface sediments was 880 ppt (Czuczwa and Hites, 1984).

Sedimentation rates in Lake Huron are generally lower than in Lakes Erie and Ontario (Kemp and Thomas, 1976a) but higher than in Lake Superior (Thomas, 1983). There has been a significant enrichment of lead, mercury, cadmium and arsenic at the sediment-water interface, relative to background concentrations. This was related to increasing anthropogenic inputs of these metals to the sediments in recent years or to post-depositional processes (Kemp *et al.*, 1978). Robbins (1980), Thomas (1981), and Kemp and Thomas (1976a) all found lead to be consistently enriched in surficial sediments (Figure 6). Surface sediments were also enriched in cadmium over background levels (Kemp et al., 1978; Kemp and Thomas, 1976a; Robbins, 1980). Kemp and Thomas (1976a) reported that recent average cadmium concentrations (2 ppm) were double that of pre-colonial levels (1 ppm). Robbins (1980) found surficial enrichment of mercury in only a few cores in 1974-75. Most concentrations were less than 0.2 ppm and all were less than 0.30 ppm (Figure 6). In the early 1970s, Kemp *et al.* (1978) found surficial levels of arsenic to be between 19 and 26 ppm. This corresponds to enrichment factors of between 2.7 and 6.2. Robbins (1980) found only occasional surficial enrichment of arsenic in cores sampled in 1974-75.

There was insufficient resolution of total DDT and PCB profiles in cores to provide a good estimate of when inputs to the lake started but Frank *et al.* (1979b) suggested that it occurred in the early 1950s. Cores analyzed by Czuczwa and Hites (1986) indicated that there has been a considerable increase in input of total PCDDs and PCDFs since approximately 1940 (Figure 6).

2.4 ST. CLAIR RIVER/LAKE ST. CLAIR/DETROIT RIVER

The St. Clair River drains Lake Huron and flows south into Lake St. Clair. It is 64 kilometres long. The river is an important international shipping channel and is used for commercial, industrial, and domestic purposes. Several refineries and petrochemical plants discharge to the St. Clair River and the volume of these discharges is about 0.5% of the total river flow (DOE and MOE, 1985). The industrial inputs of contaminants are much greater than the municipal ones (Marsalek, 1986). There are 32 permitted discharges to the river in the U.S., including 6 municipal sewage treatment plants (IJC, 1987a). There are 12 industrial and 6 municipal dischargers on the Canadian side of the river. These point sources and non-point sources, including contaminated sediments, have led to the degradation of river water and sediments. Many toxic chemicals have been identified in a 100 metre wide area along the Ontario shore near Sarnia's chemical industrial area. High levels of chlorinated organics such as PCBs, and volatile hydrocarbons, and heavy metals such as mercury and lead have been found in sediments. Spills are a significant problem in this area. Between 1972 and 1984, 175 spills were recorded, of which 161 discharged directly into the river or a tributary (IJC, 1987b). In 1986, there were 48 spills, 10 of which were on the U.S. side of the river (UGLCCS, 1989).

The St. Clair River flows into Lake St. Clair. The average depth of Lake St. Clair is about 3.4 metres. Mean inflow from the St. Clair River accounts for 98% of the outflow to the Detroit River. The theoretical flushing time of the lake is 7.3 days. The lake supports the spawning grounds for over 30 species of fish and is one of the most heavily used sport fishing and recreation areas of the Great lakes. Until recently, the lake also supported a commercial fishery.

The Detroit River is 51 kilometres long and connects Lake St. Clair and Lake Erie. It is used extensively for shipping, recreation and public and industrial water supplies. Contamination of the water and sediments by metals and a variety of organic chemicals from municipal, agriculture and industrial waste has led to significant degradation. The majority of the sources, particularly of PCBs, are located along the U.S. shore (UGLCCS, 1989). The Rouge River is a major source of contaminants to the Detroit

River. There are many industrial outfalls, waste disposal sites, municipal, hydro, and combined sewer facilities along the shores of the Detroit River.

2.4.1 Water and Suspended Solids

Concentrations of lead and mercury increased slightly along the St. Clair River (UGLCCS, 1989). Concentrations of metals were consistently below the GLWQA objectives except for lead near Sarnia and Corunna. High levels of alkyl lead and lead were found in the water near Ethyl Corporation, an alkyl lead production plant at Corunna (Chau *et al.*, 1985). Typical lead and mercury levels in the river are between 10 and 100 ppt and between 0.1 and 1.0 ppb, respectively (UGLCCS, 1989). In unfiltered water near industrial outfalls in the St. Clair River, levels of lead were up to 2.7 ppb. Concentrations of mercury in the Detroit River were relatively constant from 1984 to 1986. Some high mercury levels have been reported for tributaries of the Detroit River. Concentrations of cadmium did not change significantly over the course of the St. Clair River (UGLCCS, 1989). The mean concentration of cadmium downstream of the Sarnia industrial area was 10 ppt, with a maximum level of 90 ppt. Over the course of the Detroit River, concentrations of cadmium increased from 23 to 35 ppt in 1987 (UGLCCS, 1989) and a concentration of 2,060 ppt was recorded in the Rouge River.

In 1985, very low levels of DDT, dieldrin, alpha-BHC, and lindane were found in the St. Clair River (Kauss and Hamdy, 1985; Oliver and Kaiser, 1986; Chan *et al.*, 1986). Even distributions indicated non-point sources. No active sources of DDT or its metabolites were identified in the Detroit River in 1983 (Kaiser *et al.*, 1985). Detectable levels of lindane were reported in Lake St. Clair (UGLCCS, 1989). Active sources of dieldrin and lindane have been reported in the Rouge River and the Trenton Channel (Kaiser *et al.*, 1985).

Several studies (Kauss and Hamdy, 1985; Oliver and Kaiser, 1986; Chan *et al.*, 1986; Chan and Kohli, 1987) have identified point sources of HCB and HCBD near Sarnia. There is a plume emanating from this area along the Canadian shore which exits the river via the Chenal Ecarte. Similar distributions were found in water for QCB and OCS (Chan and Kohli, 1987). Mean whole water concentrations above and below the source, in 1985, were 0.03 and 0.8 ppt for HCB and 90.09 and 2.3 ppt for HCBD (Chan and Kohli, 1987). The percent of HCB in the dissolved phase was much greater (90%) at the head of the river than at Port Lambton (41%). The percent of HCBD in the dissolved phase at each end of the river was very similar (95% head, 96% Port Lambton). Maximum levels near industrial outfalls on the St. Clair River (unfiltered) were 2.4 ppm HCB and 1.3 ppm HCBD, both of which are much greater than the CCREM Water Quality Guidelines of 6.5 ppb and 100 ppb, respectively (UGLCCS, 1989). Low concentrations were also identified upstream of this major source on the U.S. side of the river (Oliver and Kaiser, 1986). The typical range of concentrations reported for HCB in the St. Clair River by the UGLCCS (1989) was between 0.1 and 1.0 ppt.

Concentrations of HCB and HCBD in the mid 1980s were less in water at the head of the Detroit River than at the St. Clair River mouth. This suggests that some of these contaminants are retained, degraded or volatilized in Lake St. Clair and also that some are carried through to the Detroit River (UGLCCS, 1989). Chlorobenzene concentrations in 1986 were higher in the western basin area of Lake Erie than in southern Lake Huron (Stevens and Neilson, in press). HCB enters the Detroit River from point sources in Michigan including the Rouge River (UGLCCS, 1989). In 1983, total chlorobenzene concentrations were highest in the Rouge River and at the mouths of the Trenton Channel and the Detroit River (Kaiser *et al.*, 1985). The concentrations were 25.9, 2 and 2 ppt, respectively. HCBD was not found in the aqueous phase in the Detroit River. PCBs are ubiquitous in St. Clair River water (Kauss and Hamdy, 1985; Oliver and Kaiser, 1986; Chan *et al.*, 1986).

Typical concentrations are between 1 and 10 ppt (UGLCCS, 1989). Levels higher than those generally found in the St. Clair River have been observed on the west side at the head of the river (Chan and Kohli, 1987). In Lake St. Clair, the mean PCB concentration was reported as 1.2 ppt (UGLCCS, 1989). There was no significant difference in concentration between the outlet of the St. Clair River and the inlet for the Detroit River. In 1983, the highest levels of PCBs in the Detroit River were 2.1 ppt in the Rouge River and 3.4 and 2.1 ppt at the mouth of the Trenton Channel (Kaiser *et al.*, 1985). Several industrial volatile halocarbons are present in the Detroit River. High concentrations of these compounds coincide with zones of industrial and municipal pollution (Comba and Kaiser, 1985). For example, the highest total levels of industrial volatile halocarbons were detected at Connors Creek, 5,121 ppt, just north of Amherstburg, 3,844 ppt, and at the Detroit Sewage Treatment Plant, 3,820 ppt. The concentration range of PAHs in the St. Clair River is 1-10 ppt (UGLCCS, 1989). The Sarnia township ditch is a major source of PAHs to the river. In the Detroit River in 1983, three major sources were identified (Kaiser *et al.*, 1985) downstream of major steel manufacturing plants. The two highest concentrations of 6,100 and 5,200 ppt were detected downstream from the Rouge River. The third highest concentration was 3,900 ppt at the mouth of the Detroit River.

The St. Clair River has a high suspended sediment load. This is because of the amount of shore erosion in Lake Huron (Charlton and Oliver, 1986). Because Lake St. Clair is shallow, bottom sediments are constantly resuspended by wind and swept down the Detroit River (Charlton and Oliver, 1986).

In 1985, Chan *et al.* (1986) determined concentrations of HCBD, QCB, HCB, and OCS in suspended solids from the St. Clair River. There was a dramatic increase in chemical concentrations in suspended solids over the course of the river. The mean concentrations of HCB at the head of the St. Clair River and at Port Lambton were 2.0 and 130 ppb (ng/g) respectively. For HCBD, concentrations were 1.0 and 20 ppb. In 1985, Oliver and Kaiser (1986) analyzed water samples near industrial outfalls for HCE, HCBD, HCB, OCS and chlorobenzenes. The highest concentrations were downstream from the township ditch and near Dow and Polysar. In that area, the concentrations for HCB ranged from 23 to 40 ppm and from 9.3 to 24 ppm for HCBD. These levels are approximately two orders of magnitude greater than levels at the head of the river and downstream. In Lake St. Clair, concentrations of HCB and HCBD in the particulate fraction were higher in the central corridor of the lake connecting the two rivers (Charlton and Oliver, 1986). Mean concentrations in 1985 were 20 ppb for HCB and 4 ppb for HCBD. High levels of total chlorobenzenes in the particulate phase were found at the head of the Detroit River (0.9 ppt), downstream of Belle Isle (2 ppt), and at the mouth of the Detroit River (1.2 ppt) in 1983 (Kaiser *et al.*, 1985). In 1985, the mean particulate concentration of PCBs in lake St-Clair was 36 ppb (Charlton and Oliver, 1986) with higher concentrations on the west side of the lake. In the mid 1970s, PCB concentrations in suspended solids were higher in the Detroit River than in Lake St. Clair (Frank *et al.*, 1977). These ranked with the Niagara River as the highest levels in the Great Lakes (Frank *et al.*, 1981b). The short residence time of the Detroit River may cause an uncharacteristically high fraction of PCBs to be found in the aqueous phase. In 1983, the highest levels of PCBs in the particulate phase (2.8 ppt), were identified just downstream from Belle Isle and at the mouth of the Trenton Channel (Kaiser *et al.*, 1985) and levels were 10 times higher at the Rouge River and Trenton Channel than on the Canadian side.

A higher proportion of PAHs was associated with suspended solids in the Detroit River than PCBs, probably because some PAHs enter the river as particles (Kaiser *et al.*, 1985). The highest concentrations of particulate PAHs in 1983 were downstream from Belle Isle (1.3 ppt), adjacent to Fighting Isle (1 ppt) and at the mouth of the Detroit River (1.3 ppt) (Kaiser *et al.*, 1985).

2.4.2 Bottom Sediments

Sediment accumulation is low in the St. Clair and Detroit Rivers. Less than 1% of contaminant movement is by bottom sediment movement (UGLCCS, 1989). High concentrations of certain toxic chemicals were found consistently in the sediments adjacent to the Sarnia industrial complex on the Canadian side of the St. Clair River. There was a major chemical release in 1985 which consisted mainly of perchloroethylene and carbon tetrachloride. Because these chemicals are volatile, they are only found in sediments near major source (Oliver and Pugsley, 1986). After the spill, high concentrations were observed in the bottom sediments mainly on the Canadian side of the river. During the investigation of this spill, a large area of non-aqueous puddles overlying the sediments was found downstream of Dow (Carey and Hart, 1986).

In Lake St. Clair, the centre of the lake is the area of greatest recent accumulation of chemicals. The sediments are only a temporary reservoir before they are resuspended and moved down the Detroit River. Because of the non depositional nature of Lake St. Clair, the sediments are responsive to changes in loadings. Usage of PCBs, mercury and DDT was curtailed in the early 1970s. Following this, there was a significant decrease in mean concentrations of these compounds between 1970 and 1974 (Thomas *et al.*, 1975). Mean concentrations of mercury in bottom sediments decreased from

1.5 to 0.6 ppm, mean DDT from 3.6 to 1.5 ppb and mean PCBs from 19 to 10 ppb. By 1985, the decrease in concentrations of mercury was more pronounced (Figure 7).

Contaminated sediments in the Detroit River occur mainly along the U.S. side of the river downstream from the City of Detroit. The sediment deposited at the mouth of the Detroit River is ultimately resuspended and transported to the depositional zones of Lake Erie.

Lead levels in sediments of the St. Clair River and Lake St. Clair are generally low. Exceptions occur adjacent to:

(1) The Ethyl Corporation on the St. Clair River where levels up to 339 ppm lead have been reported in sediment samples;
(2) In sediments of the Black River;
(3) Across the river from the Lambton Generating Station; and
(4) In the eastern distributary of the St. Clair Delta (UGLCCS, 1989, Mudroch *et al.*, 1985).

Lead levels in bottom sediments of the Detroit River are often higher than the dredge spoil guideline of 50 ppm. In 1980, high levels were found adjacent to Windsor and along the Michigan side of the river (Hamdy and Post, 1985). Concentrations at the mouth of the Rouge River (200 ppm) were higher in 1980 than in 1970 (50 ppm). In two studies done in 1982, the highest levels were found in the southern part of the river (Lum and Gammon, 1985; Fallon and Horvath, 1985). In 1983, levels of lead in Detroit River sediments were higher than those in Lakes St. Clair and Erie (Mudroch, 1985). The highest concentration (700 ppm) in 1983 was in the surficial sediments at the Rouge River mouth and high levels were also found west of Fighting Island and Belle Isle. In 1982 and 1985, concentrations of lead were highest (> 200 ppm) in the upper part of the river (above the Rouge River) and in the Trenton Channel (UGLCCS, 1989). Some of the highest maximum levels found in the river were 960 ppm in 1982 (Lum and Gammon, 1985), 704 ppm and 546 ppm in 1983 (Mudroch, 1985; Chau *et al.*, 1985), and 1,750 ppm in 1982 and 1985 (UGLCCS, 1989).

Mercury has been one of the main contaminants in this connecting channel. Levels of mercury in the bottom sediments of the St. Clair River peaked in the late 1960s and early 1970s with maximum levels of 1,470 ppm.

The main source, was the Dow chlor-alkali plant, which ceased production in 1973. However, some mercury is still entering the river from the area. In the early 1970s, high levels were also found at the mouth of the Black River (Fitchko and Hutchinson, 1975). By 1977, the concentration at the Dow site had dropped to 58 ppm (IJC, 1987a). However, concentrations up to 51 ppm were found in the mid-1980s indicating that there are still inputs (UGLCCS, 1989). Sediments at the lower end of the river still have concentrations of mercury in excess of dredge spoil guidelines (UGLCCS, 1989). Decreases in mercury concentrations in the Detroit River from 1970 to 1980 reflect reduced upstream loadings of mercury. The largest changes in concentrations occurred in the upper section of the river, above Zug Island. The mean concentrations in bottom sediments were 3.73 ppm in 1970 and 0.4 ppm in 1980 (Hamdy and Post, 1985). In the mid 1980s, the highest mercury levels in bottom sediments were in the Trenton Channel (> 3.0 ppm) and adjacent to Belle Isle (> 2.5 ppm) (UGLCCS, 1989).

Cadmium concentrations in the sediments of the St. Clair River are generally low and suggest that there are no point sources (UGLCCS, 1989). Concentrations of cadmium are greater in Lake St. Clair sediments than in Lake Huron sediments (UGLCCS, 1989). In 1980, concentrations of >6 ppm cadmium were recorded at several locations along the Michigan side of the Detroit River (Hamdy and Post, 1985). In 1982, levels of cadmium >10 ppm were detected at the mouths of the Detroit and Rouge Rivers (Lum and Gammon, 1985). Also in 1982, Fallon and Horvath (1985) reported that the highest concentrations of cadmium were in the southern part of the Trenton Channel. In the mid 1980s, peak concentrations of cadmium were found adjacent to Belle Isle and the Rouge River and in the Trenton Channel (UGLCCS, 1989). Maximum levels ranged from 25 to 96 ppm and the data suggested that there were still sources of cadmium to the Detroit River (UGLCCS, 1989).

In 1970 and 1974, the mean concentrations of arsenic in the bottom sediments of Lake St. Clair were 2.5 and 3.4 ppm respectively (Thomas *et al.*, 1975). In the Detroit River, the mean concentration of arsenic in the mid 1980s was 10 ppm and the peak level was 54 ppm in the Rouge River (UGLCCS, 1989).

In Lake St. Clair, concentrations of DDT decreased from 6.6 ppb to 2.4

ppb between 1970 and 1974. The highest concentrations were found at the outlet of the lake at both times. In 1982, Oliver and Bourbonniere (1985) found that mean levels of DDT and its metabolites were lower in Lake St. Clair than in southern Lake Huron or Lake Erie.

In 1970 and 1974, 24% of sediment samples from Lake St. Clair had detectable levels of dieldrin (Frank *et al.*, 1977). In the Detroit River, in 1980, dieldrin was detected in only 22% of the samples (Hamdy and Post, 1985) and the maximum level was 35 ppb. In 1985, the highest levels of up to 55 ppb were found adjacent to the Canard River mouth (UGLCCS, 1989).

Alpha-BHC and lindane tend to remain in the aqueous phase so sediment concentrations are low. Oliver and Bourbonniere (1985) detected low concentrations in 1982 in southern Lake Huron, Lake St. Clair and Lake Erie. In an earlier study by Frank *et al.* (1977), lindane was not detected in any samples from Lake St. Clair. In 1980, in the Detroit River, alpha-BHC and lindane were detected in 52% and 27% of the sediment samples respectively (Hamdy and Post, 1985). In a 1984 study, concentrations of HCB and HCBD in St. Clair River sediments were reported to be highest in areas adjacent to the Sarnia industrial zone (Figure 8)(DOE and MOE, 1986). For example, the highest concentrations of HCB in bottom sediments near Dow were 24 ppm with an average concentration of 5.2 ppm. Mean concentration of HCB for the reach 35 km downstream was 370 ppb. The maximum HCBD concentration was 46 ppm with a mean concentration of 750 ppb and a downstream level of 190 ppb. Similar results were found in 1985. Concentrations of HCBD in near shore sediments rose from less than the minimum detection level to more than 1 ppm downstream of the town ditch (Oliver and Kaiser, 1986).

In 1983, levels of OCS in the bottom sediments were also highest in the area adjacent to the Sarnia industrial complex followed by a plume in Lake St. Clair emanating from the delta (Pugsley *et al.*, 1985). Six locations in the river and four in the lake had concentrations of OCS greater than 10 ppb. Oliver and Bourbonniere (1985) reported that bottom sediment concentrations of HCB in southern Lake Huron were about 1 ppb in 1982 and concentrations in Lake St. Clair had a mean level of 68 ppb (top 3 cm). The difference for HCBD was 0.08 ppb in Lake Huron and a mean level of 7.3 ppb in Lake St. Clair. In 1985, mean concentrations of HCB in Lake St. Clair were 21 ppb (top 1 cm) and 5 ppb for HCBD (Charlton and Oliver, 1986). The concentrations of HCB and HCBD in Lake St. Clair are still increasing, or at least not dropping significantly (UGLCCS, 1989). High levels of HCB (up to 140 ppb), were found in 1985 in the Detroit River adjacent to the Rouge River, in the Trenton Channel and at the mouth of the Detroit River but no major point sources have been identified (UGLCCS, 1989). A similar distribution was found in 1983 for total chlorobenzenes, except for a high concentration (3,500 ppb) west of Fighting Island (Kaiser *et al.*, 1985).

Mirex was not detected in Lake St. Clair in 1982 (Oliver and Bourbonniere, 1985) or the Detroit River in 1980 (Hamdy and Post, 1985). Dioxins and furans were detected in sediment samples collected in the mid-1980s from the St. Clair River (DOE and MOE, 1985, 1986; UGLCCS, 1989). The highest concentrations were found in the Township ditch and the 1st Street sewer. The octa- and hepta- congeners predominated and 2,3,7,8-TCDD was not detected.

A review of PCBs in St. Clair River sediments concluded that a temporal trend could not be assessed because of the variations in the studies (Pugsley *et al.*, 1985). However, there was an increase in concentration at the Polysar-Dow area of the St-Clair River (on the Canadian shore), (DOE and MOE, 1986) (Figure 8). The maximum levels were considerably higher than the dredge spoil guideline of 0.05 ppm. Other areas where there is PCB contamination include the vicinity of Ontario Hydro's Lambton generating station on both sides of the river and in the Belle River (UGLCCS, 1989). The range of concentrations along the American shore was relatively low. Oliver and Bourbonniere (1985) did not detect an increase in the concentration of PCBs in sediments between southern Lake Huron and Lake St. Clair. In 1982, mean concentrations of PCBs in Lake St. Clair sediments were much lower than those reported for western Lake Erie (Oliver and Bourbonniere, 1985).

The Detroit River is a major source of PCBs to Lake Erie (Oliver and Bourbonniere, 1985). PCBs enter the river from Lake St. Clair and there are several point sources along the river. In 1980, PCBs were found in 78% of the bottom sediment samples (Hamdy and Post, 1985). The highest concentrations (> 500 ppb) were found along the Michigan shore, south of Detroit. In 1982, the highest levels were found at the head of the river (Fallon and Horvath, 1985). This was thought to reflect the effect of Lake St. Clair and a nearby wastewater treatment plant. In 1983, Pugsley *et al.* (1985) reported higher concentrations of PCBs in 10 cm bottom sediments from Lake St. Clair than in the Detroit River. Kaiser *et al.* (1985) found the highest concentrations in 1983, 200 to 230 ppb, to be at the mouth of the Rouge River, southeast of Belle Isle, and at the mouths of the Trenton Channel and Detroit River. There are also high levels and possible sources of PCBs downstream of Belle Isle (IJC, 1987a) and adjacent to the Ecorse River (UGLCCS, 1989).

In 1985, PAHs were detected in bottom sediments of the St. Clair River adjacent to Dow at levels up to 60.79 ppm and averaging 3.31 ppm (Nagy *et al.*, 1986). Levels up to 140 ppm were reported in the UGLCCS (1989). High levels of PAHs have been identified across the river from Lambton Generating Station and in some tributaries on the U.S. side of Lake St. Clair (UGLCCS, 1989). High levels of PAHs were found in the 1980s in the Detroit River, especially downstream of Belle Isle, in the vicinity of Grosse and Fighting Islands, and in the lower Rouge River (Fallon and Horvath, 1985; Kaiser *et al.*, 1985; UGLCCS, 1989). The highest concentrations reported by Kaiser *et al.* (1985) were between 20 and 33 ppb. Coal-fired power plants and steel mills are the likely sources.

Subsurface maximum concentrations in most core samples from the connecting channels have been included in this report. Exceptions are mercury in a 1986 core from 1986 Chenal Ecarte (Mudroch and Hill, 1987) and HCB and HCBD in the mid-1980s adjacent to Dow (DOE and MOE, 1986). Even though concentrations are decreasing in many cases, surface levels are far higher than background levels. Cores with decreased surface concentrations are as follows, by chemical, date of sampling, and geographic location: mercury, 1986, adjacent to Sarnia (Mudroch and Hill, 1987); mercury, 1985, central Lake St. Clair (Mudroch and Hill, 1987); DDT, 1985, Lake St. Clair (UGLCCS, 1989); HCB and HCBD, mid 1980s, vicinity of Dow (DOE and MOE, 1986); PCBs, 1985, Lake St. Clair (UGLCCS, 1989); and PAH, 1985, St. Clair River (Nagy *et al.*, 1986).

2.5 LAKE ERIE

Lake Erie is the fourth largest of the Great Lakes by area. It is the smallest by volume and also the shallowest. It is divided into three basins. The western basin, into which the Detroit River flows, is very shallow but has the most important fish spawning and nursery grounds. It is downstream from the Canadian chemical companies on the St. Clair River, downstream from Detroit, and has Toledo on its shores. Thus, this part of Lake Erie is the most likely to be affected by chemical contamination. Limnologically, Lake Erie is different from the other four, deeper and essentially oligotrophic Great Lakes. Lake Erie is mesotrophic and approached a eutrophic status in the 1960s. It has a high nutrient load, relative to its volume. Combined with its shallow depth and high biological productivity, it processes contaminants differently from the other four lakes. The greater productivity in Lake Erie may has several possible consequences: the biomass may dilute the chemicals; the organic-rich suspended particulates may compete for toxic metals and hydrophobic organic chemicals; the sedimentation and burial rates are higher; and photochemical and biological degradation of chemicals is perhaps greater. The rapid flushing of the lake (see Table 1) also accounts for the lower concentration of contaminants in the water column. The net result is that although loads of chemicals such as PCBs to the lake are similar to Lake Ontario (Strachan and Eisenreich, 1988), the bioaccumulation of these chemicals has been less.

Lake Erie has been heavily contaminated by metals. It is probably the second most heavily contaminated with metals of the Great Lakes (after Lake Michigan) based on overall concentrations (Rossmann, 1984). The relative occurrence of dissolved metal concentrations was highest in Lake Erie (Rossmann and Barres, 1988). Lake Erie also had the highest total concentrations of the greatest number of metals.

2.5.1 Water and Suspended Solids

Data on toxic chemical concentrations in water in Lake Erie are shown in Table 10. Rossmann (1984) reviewed the available data on total and dissolved lead in Lake Erie water. For water collected at unrecorded depths, the 1974 and 1980 medians were at the minimum detection level (5 to 10 ppb) (n = 6). There were no trends in total lead in epilimnion water, taken at depths of less than 5 m. Mean concentrations in 1967, 1973, 1975, 1978 and 1979 ranged from 0 to 9 ppb. These early data and those in Table 10 cannot be taken as evidence of a decrease in lead concentrations but probably reflect sample contamination problems in the earlier studies. Sonzogni and Simmons (1981) arrived at the same conclusion when comparing data from 1967 with those from 1970 to 1977. In 1978, mean concentrations of dissolved lead were as high as 23 ppb and a maximum of 840 ppb (n = 717) had been recorded. Again, these historical data are unlikely to be accurate (Rossmann, 1984). Nevertheless, there may be a trend in concentrations of total mercury. Data from the 1970s suggest that mean concentrations of total mercury were as high as 370 ppt (median 37 ppt and maximum 130 ppb (n = 618) in 1978). There was a mean concentration of 170 ppt (n = 170) in 1970-71; 370 ppt (n = 618) in 1978; 81 ppt (n = 596); in 1979; and 42 ppt (n = 11) in 1981. Rossmann (1984) calculated that total mercury concentrations in epilimnetic water were decreasing at a mean rate of 12 ppt/year. The reason for these changes is more likely to be the improvement in analytical accuracy. Mean values of dissolved cadmium in 1963 and 1964 were reported as 10 ppb (n = 49) (the minimum detection level). In the 1970s, mean concentrations of dissolved cadmium were reported as 1.1 ppb (1970; n = 9); 0.7 ppb (1971; n = 112); 2.5 ppb (1978; n = 708); 0.7 ppb (1979; n = 567). The latter value for 1979 is still an order of magnitude higher than the mean dissolved concentration of 71 ppt measured in 1981 (Table 10). In 1978, Lum and Leslie (1983) reported that 87% of the total cadmium in Lake Erie water was in the dissolved phase. In 1981, Rossmann (1984) found the concentration of dissolved cadmium was lowest in the waters of the central basin, but insufficient samples were collected to justify this statistically. Lum (1987) compared Rossmann's (1984) data for 1981 (71 +/-27 ppt) with his data for 1978 (40 +/- 20 ppt) and for 1984 (29 +/- 15 ppt). Cadmium concentration may be decreasing because these data are considered to be reliable, although there may still be methodological problems. Rossmann quotes a value of 1.0 ppb (n = 2) for total arsenic in water from unrecorded depths for 1975. In 1980, a mean value of 10 ppb arsenic (n = 6) was recorded but this was the minimum detection level. Mean concentrations in 1981 were about half of what could have been predicted from measurements made in the late 1970s. Rossmann calculated the rate of decrease of arsenic concentrations was 310 ppt/year between 1978 to 1981.

There are limited data available on the concentrations of toxic organic chemicals in the waters of Lake Erie (Table 10). Nearly all early values were below the minimum detection levels of the analytical techniques used prior to the early 1980s. For DDT, Konasewich *et al.* (1978) reported open lake water values close to or less than the minimum detection level of 1 ppt. In 1981, McCrea *et al.* (1985) used large water volume extraction procedures and reported that p,p'-DDT was detectable at all of his sample stations and was present almost exclusively in the aqueous phase. Between 1981 and 1983, DDE was detected at concentrations of 0.1 ppt (Oliver and Nicol, 1984). In 1981, Filkins *et al.* (1983) reported p,p'-DDT and p,p'-DDE concentrations ranging from 0.007 to 0.022 ppt and from 0.006 to 0.018 ppt respectively (n = 5). In 1986, Lake Erie surface water DDE concentrations ranged from less than the minimum detection level to 0.08 ppt (IJC, 1987). McCrea *et al.* (1985) reported that 94% of the dieldrin in Lake Erie surface water was in the aqueous phase in 1981. Concentrations were reported as between 0.069 and 0.0934 ppt. McCrea *et al.* (1985) reported that 100% of lindane was present in the aqueous phase. Oliver and Nicol (1984) reported total concentrations of 4.2 ppt alpha-BHC and 0.38 ppt gamma-BHC in water from Fort Erie in 1981-1983. No mirex was found in water from the eastern area of Lake Erie by McCrea *et al.* (1985). Eadie (1984) stated that 90% of the PAHs in the waters of Lake Erie were in the dissolved phase and that a substantial portion of the low-solubility PAH was associated with suspended solids only in nearshore areas. Near Buffalo, in 1976, B[a]P and total PAH were found at concentrations of 0.3 ppt and 4.7 ppt, respectively (Basu and Saxena, 1978).

There are many sources of PCBs to Lake Erie, including industrial and municipal outfalls, land and urban runoff, landfills, resuspension and translocation of contaminated lake bottom sediments and the atmosphere. From 1972 to 1978, five independent groups reported that concentrations of total PCBs in Lake Erie waters were below the minimum detection level of 100 ppt, while one lake-wide survey in 1972 reported a mean value of 27 ppt (Glooschenko *et al.* 1976). Also, a nearshore mean value of 20 ppt was reported for 1974-75 (Konasewich *et al.*, 1978). Both of these values were at the minimum detection levels (Sonzogni and Simmons, 1981). In 1981, McCrea *et al.* (1985) reported that 100% of the PCBs in Lake Erie water were in the aqueous phase. Between 1981 and 1983 Oliver and Nicol (1984) detected various PCB isomers at 0.49, 0.46 and 0.25 ppt in water from Fort Erie. Clearly, by the early 1980s, the minimum detection level of 100 ppt that had been used in the mid 1970s could not be used for detecting trends of PCB in water. Filkins *et al.* (1983) detected PCBs at 0.13 to 0.78 ppt (n = 5). The spatial distribution of PCBs in Lake Erie showed that the highest concentrations of >2.5 ppt were at the extreme western end of the lake (Stevens and Neilson, in press). Most of the western basin had concentrations higher than those found in Lake Ontario. The IJC (1987b) reported surface water PCB values of 0.29 - 2.96 ppt. If the data for 1972 to 1975 are reliable, then the decrease from approximately 23 ppt in the early 1970 to approximately 1.4 ppt in 1986 could be evidence of a dramatic decrease in PCB concentrations.

Starting in the late 1970s concentrations of the numerous volatile industrial organic chemicals which are present in the dissolved state were determined in water from the lower Great Lakes. Concentrations were highest in the western-central basin of Lake Erie. For example, levels over 30 ppt of carbon tetrachloride were detected in 1978 (Kaiser and Valdmanis, 1980). Continual inputs of volatile chemicals must occur to maintain concentrations. In 1977 and 1978, mean concentrations of dichlorodifluoromethane were 76 and 73 ppt; 34 and 46 ppt trichlorofluoromethane; 15 ppt chloroform; 19 and 37 ppt carbon tetrachloride; and 20 and 11 ppt trichloroethlyene, respectively, in Lake Erie (Kaiser and Valdmanis, 1980).

The available data on contaminants in suspended solids are summarised in Table 11. Suspended material in Lake Erie originates from shoreline erosion, river inputs, aeolian material, autochthonous organic matter production and bottom sediment resuspension. Lake Erie has TSM concentrations of 2-6 mg/L, compared to Lake Ontario (1-4 mg/L), Lakes Huron and Michigan (0.5-2 mg/L), and Lake Superior (0.2-1 mg/L) (Eadie and Robbins, 1987). As discussed in the introduction, this may reduce bioaccumulation in Lake Erie. This is supported by Rossmann and Barres (1988), who reported that Lakes Erie and Ontario had the highest concentrations of toxic metals in the particulate fraction. Lake-wide concentrations of particulate cadmium were 2.4 ppm (n = 54) in 1978 and 1984 compared to 1.7 ppm (n = 14) measured at the Niagara River inflow at Lake Erie, indicating a retention of some particulate cadmium in the lake, most likely in the deep eastern basin (Lum, 1987).

Data on organic chemical in suspended solids are scarcer than on toxic metals (Table 10). Most of the concentration data on organic chemicals are from Strachan and Eisenreich (1988) who carefully reviewed all published values to select reliable values for use in predictive models. The most recent reliable data are those of Stevens and Neilson (in press).

2.5.2 Bottom Sediments

Data on chemical concentration for Lake Erie bottom sediment are summarised in Table 11. Two studies on concentrations of toxic chemicals in bottom sediment have been conducted in Lake Erie, one in 1971 (Frank *et al.*, 1977; Thomas and Mudroch, 1979) and one in 1979 (Rathke, 1984). The 1971 samples were the surface 3 cm, while the 1979 samples used the surface 10 cm. Therefore, direct comparison between the studies is not possible. However, because the more contaminated 1971 sediments were being buried by less contaminated sediments in the late 1970s, the collection of a 3 cm sample in 1979 might have revealed an even greater decrease in concentrations than that seen in the 10 cm samples. Data on metals in the surface 3 cm of surficial sediments show that lead, cadmium and mercury concentrations in the lower Great Lakes are higher over larger areas of the lake bottom than in the three upper Great Lakes. In 1971, large areas of the lake bottom had concentrations of lead greater than 150 ppm (Thomas, 1981), whereas in 1979 only small areas had concentrations greater than 100 ppm (Rathke, 1984). In the central basin, where concentrations in 1971 had been greater than 100 ppm, levels have decreased to less than 75 ppm, presumably because of downstream transport burial, dilution or dispersion downstream of the historically contaminated sediments. The 1971 survey showed two lead plumes, one from Detroit to the western basin and one from Cleveland to the central basin (Thomas, 1981). In 1970, Konasewich *et al.* (1978) reported levels of 340 and 420 ppm for Cleveland and Buffalo Harbours respectively. The same effect can be seen in cadmium (Figure 9). Background (pre-colonial) bottom sediment concentrations of cadmium in Lake Erie are 0.1 to 1.7 ppm. Surface sediment concentrations of cadmium in nearshore areas were between 0.1 and 8.3 ppm and between 0.2 and 0.3

ppm in harbours (Fitchko and Hutchinson 1975; Mudroch *et al.*, 1985). The average concentration of cadmium in lake bottom sediment for western Lake Erie was reported as 6.6 ppm (Nriagu *et al.*, 1979). The pattern for mercury in Lake Erie sediments is also similar. In 1971, a small area of the western basin of Lake Erie had concentrations of mercury in bottom sediments of greater than 2 ppm mercury and a large area was over 1 ppm (Thomas and Jacquet, 1976). By 1979, the anomaly was farther out into the west basin away from the inflow of the Detroit River and the area with a concentration greater than 1 ppm mercury had decreased considerably, indicating a rapid recovery from earlier contamination (Rathke, 1984). There was little change in the mercury concentration in suspended solids entering Lake Erie from the Detroit River during 1974 (Thomas and Jacquet, 1976), when the mean value was 1.06 ppm. In 1971, mean surficial sediment mercury concentrations in the west basin were 1.14 +/- 1.28 ppm compared to 0.60 +/- 0.42 ppm in 1979. The comparable values for lead, cadmium and arsenic were 86 +/- 48 and 56 +/- 36 ppm; 5.6 +/- 3.5 and 3.0 +/- 2.4 ppm; and 7.9 +/- 2.5 and 6.5 +/- 3.0 ppm respectively.

Data on the concentrations of organic chemicals in surficial sediment from Lake Erie are shown in Table 11. In 1971, the distribution of organic chemicals in surficial sediments showed that the highest concentrations of hydrophobic chemicals, such as DDE and dieldrin, were found in a plume originating from the Detroit River. TDE was the predominant compound of the DDT group in the top 3 cm of bottom sediment samples from 1971. The mean TDE lake value was 18.4 ppb with a range of 0.3 to 186 ppb. Both TDE and DDE concentrations were 2 to 3 times higher in the depositional basins than in the other parts of the lake. The highest concentration of TDE was 46.5 ppb in the western basin. The concentration of DDE was 22.1 ppb, giving a total TDE and DDE value of 68.6 ppb. In 1980, DDE was 8 ppb, DDE was 2 ppb and DDT was 1 ppb (a total of 11 ppb) in the upper 3 cm of sediment from a site in the western basin. (Anderson, 1980). Oliver and Bourbonniere (1985) reported that p,p'-DDD were evenly distributed across Lake Erie. The sum of dichloro- through to hexachlorobenzenes in Lake Erie sediment was 26 ppb, less than in Lake Huron (38 ppb) and Lake Ontario sediment (560 ppb) (Oliver and Nicol, 1982). In 1982, 3 cm samples from the western, central and eastern basins of Lake Erie had concentrations of HCB of 9.1 ppb (range 4.6 - 17 ppb); 2.4 ppb (range 1.2 - 3.7 ppb); and 2.7 ppb (range 1.4 ppb - 5.2 ppb), respectively (Oliver and Bourbonniere, 1985). In the same samples, they detected HCBD at concentrations of 1.6 ppb (0.7 - 3.2 ppb); 0.2 ppb (0.1 - 0.4 ppb); and 0.2 ppb (0.1 - 0.6 ppb) respectively, or an overall depositional basin mean of some 0.7 ppb. In 1982, concentrations of total PAHs in the adjacent Raisin River in western Lake Erie ranged from 530 to 770 ppb (Eadie *et al.*, 1982). Extreme concentrations of between 4.8 to 390 ppm PAH were found in sediments from the Black River, near steel industries. The distribution of PAHs in the three basins of Lake Erie (Nagy *et al.*, 1989) showed that the highest concentrations of B[a]P were 200 ppb in the central basin. Concentrations of PCDDS and PCDFs in Lakes Erie, Ontario, Huron and Michigan were determined by Czuczwa and Hites (1986). The main isomer present was OCDD, followed by H7CDF. Concentrations of OCDD in Lake Erie were 1,700 and 2,000 ppt compared to 4,800 ppt for Lake Ontario, 780 and 960 ppt for Lake Michigan, and 880 ppt for Lake Huron. OCDF concentrations were much lower in Lake Erie than in Lake Ontario. Data on PCBs in surficial lake bottom sediments are the most extensive (Table 11). The highest levels were in the western basin and were associated with inputs from the Detroit River.

Concentrations of mercury and lead increased rapidly after 1935 in cores collected in 1971. Concentrations of mercury increased most rapidly after 1955. Based on these analyses, the sediment concentration of mercury in 1971 was 12.4 times that in pre-colonial sediments (Kemp and Thomas, 1976a). In surface sediments, concentrations of lead were 4.4 times and concentrations of cadmium were 3.6 times precolonial levels. More recent data show that this trend has been reversed. Data on lead in a dated core from the eastern basin of Lake Erie show that concentrations began to increase slowly from about 3 ppm at the turn of the century to the 1940s, rose rapidly to approximately 30 ppm in 1950, peaked at 58 ppm in the early 1970s, and have since decreased to 30 ppm. This is similar to concentrations in about 1955 (Eddie and Robbins, 1987) (Figure 10). Cores collected in 1985 have shown that concentrations of arsenic have decreased from 13 to 9 ppm in bottom sediments (Legault, 1986). Peak arsenic concentrations occurred in approximately 1955 and since then have decreased to concentrations similar to those which were recorded in 1945. Thus, sediment cores from Lake Erie indicate that there has been a recovery from earlier contamination. In 1971, p,p'-DDE was found at a depth of 10-12 cm (corresponding to about 1958-60) (Figure 10) (Frank *et al.*, 1977). In the same core TDE was first detected at a depth of 6-8 cm, representing 1961-1963. Concentrations of DDE and TDE then increased rapidly to surface concentrations of 19 and 53 ppb, respectively. Ten years later, Anderson (1980) reported that the upper 3 cm of sediments in a core from the eastern basin had DDT, DDE and DDD concentrations of 1 ppb, 2 ppb and 8 ppb, respectively. The highest concentrations of total DDT was 23 ppb at a depth of 15 cm. Beneath this depth, concentrations fell to 15 ppb total DDT at 35 cm depth. The high sedimentation rates in Lake Erie allow for good resolution of trends of inputs of dioxin and furans. In two cores, the maximum input of PCDDs and PCDFs was in the mid 1970S (Czuczwa and Hites, 1986). Following the mid 1970s, inputs decreased (Figure 10). Extrapolation to deeper layers and times of sediment deposition indicated that initial inputs of PCDDs and PCDFs to Lake Erie probably occurred in the mid to late 1930s.

In 1971, PCBs were in sediment deposited during 1954-1956 in a core from the Toledo area. The upper layers had progressively rapidly increasing PCB concentrations of up to 340 ppb for the layers being deposited in 1971 (Frank *et al.*, 1977). In 1982, the surface 3 cm of sediment for the western, central and eastern basins of Lake Erie had PCB concentrations of 300 ppb (range of 140-660 ppb), 131 ppb (range 38-190 ppb), and 91 ppb (range 37-140 ppb) (Oliver and Bourbonniere, 1982). These values can be compared with the mean concentrations of 252 ppb in 1971 in the surficial sediment (3 cm) from the western basin (Frank *et al.*, 1977). The reasons for this may be that the surficial sediments of the western basin are thoroughly mixed (Eadie and Robbins 1987) or the inputs of PCBs have not decreased significantly.

2.6 NIAGARA RIVER

The Niagara River connects Lake Erie to Lake Ontario. It is a short connecting channel of approximately 60 km with a very high discharge rate. The river is divided into upper and lower reaches by Niagara Falls. The main sources of contamination to the river are point source discharges from steel and petrochemical industries and municipal wastewater treatment plants (Figure 11). These treatment plants receive effluents discharged from industries. The large petrochemical industries on the U.S. side of the river have produced a variety of chlorinated industrial organic chemicals and pesticides. Most of the wastes from these industries have been buried in waste landfills such as Hyde Park and Love Canal. These sites now produce leachate which enters the Niagara River.

Data on the contamination of Niagara River and downstream Lake Ontario were published in a special volume of the Journal of Great Lakes Research (Allan *et al.*, 1983). Numerous papers and reports have since been published on this subject. The Niagara River was the subject of the bi-national Niagara River Toxics Committee Study (NRTC, 1984) which described the contamination of the river in great detail. The NRTC (1984) identified 261 synthetic chemicals in the ecosystem and reported that 1400 kg of pollutants were discharged to the river from municipal and industrial point sources and that 89% of the total came from U.S. sources. It also reported that 61 U.S. hazardous waste disposal sites and 5 Canadian landfills had the potential to contaminate the river (and downstream and that 28 of these contribute contaminants to the river and that groundwater contamination covers a large area along the U.S. side of the river. Since the release of this report, Canada and the U.S. have agreed to a plan which has a goal of 50% reduction of selected persistent toxic chemicals from both point and non-point sources by 1996.

In general, the longer term monitoring data on suspended solids and the more recent data on water quality are the best long term (1979 for metals) (1980 for organics) water quality data on toxic chemicals in the Great Lakes. The data indicate that concentrations of many contaminants have decreased. This decrease can also be seen in the bottom sediments of Lake Ontario and is discussed later.

Between 1981/2 and 1986/7, the point source loadings to the Canadian side were estimated to have decreased by 60% (MOE, 1987). On the U.S. side, an 80% reduction in total organic and inorganic priority pollutants from point sources was estimated to have taken place between 1981/82 and 1985/86 (NYDEC, 1987). A significant proportion of these decreases were related to plant closures or process shut-downs (NYDEC, 1987). In 1984, no assessment could be made of the loadings of toxic chemicals from groundwater from 215 hazardous waste sites (NRTC, 1984).

Further study concluded that 61 of the 164 sites within 5 km of the river have the potential to contaminate it (NRTC, 1984). Of the 17 landfill sites on the Canadian side, 5 have the potential to contaminate the Niagara River (Koszalka *et al.*, 1985). Although estimates of inputs have been made, there are large uncertainties involved and more sampling and modelling is needed to calculate loadings accurately. The existing calculations are based on 70 sites on the U.S. side of the river and estimate that a total of 180 kg/day of organic compounds are discharged. Thus, there is a possibility that the contribution from non-point groundwater sources of chemicals could be as high as that from point sources. The four major superfund sites of 102nd Street, Love Canal, S-area and Hyde Park contain a total of 304,000 tonnes of chemical wastes. They are hydraulically connected to the river and have been associated with off-site migration of chemicals (Brooksbank, 1987). Several of the small tributaries to the Niagara River have bottom sediments with high concentrations of toxic contaminants and these could be long term sources of contaminants to the river.

Contamination of the Niagara River has been studied very intensively. This is because the Niagara River was the first area in which there was a major chemical crisis (1980), that of Love Canal. In the late 1970s, monitoring for concentrations of metals in suspended solids was initiated in Canada. By the early 1980s, this had been extended to organic chemicals in suspended solids at the mouth of the Niagara River. Later, in the mid 1980s, more sophisticated aqueous phase analyses were performed. These developments required new sampling and analytical techniques which have since been extended throughout the Great Lakes.

By 1984, monitoring had been initiated both upstream at Fort Erie and downstream at Niagara-on-the-Lake (NOTL) to calculate mass balances of specific toxic chemicals in the river. Meanwhile, several special studies of chemicals in the river have been conducted by federal and provincial (Ontario) Canadian agencies. A summary of the differential concentrations between Fort Erie and NOTL (Table 13) is based on values agreed to by the responsible Canadian and U.S agencies. There has been considerable debate about sampling, analytical and data manipulation techniques to arrive at these estimates. Loadings of 25 chemicals were considered to be significantly higher at the NOTL location, either in the water or suspended sediment fractions or both in 1984/86 and 1986/87. Regardless of the exact numbers for specific compounds, it is clear that large amounts of chemicals have been or are still being introduced to the Niagara River.

Between 1984 and 1987, Environment Canada collected data on water and suspended solids concentrations at NOTL and Fort Erie. The objective was to assess the differential loads of toxic organic chemicals added along the course of the Niagara River. Two reports have been released, the first for Dec. 1984 to March 1986 and the second for April 1986 to March 1987. Collectively, the data in these reports on organic chemicals concentrations in the water and suspended solids at NOTL and Fort Erie represent the most comprehensive data base of its type anywhere in the world. Suspended solids were sampled by high speed centrifugation. Concentrations in the aqueous fraction are based on a continuous extraction system over a 24 hour period. A value for recombined water (RWW) was calculated from the aqueous concentrations and the suspended solids concentrations based on the suspended solid content of the water. Using these values for RWW, 21 of the organic chemicals exceeded the strictest water quality criteria at least once, 15 at both NOTL and Fort Erie, 3 at Fort Erie only.

2.6.1 Water and Suspended Solids

Between 1975 and 1979 less than 10% of the samples analyzed at the mouth of the Niagara River exceeded the 1978 Water Quality Agreement (GLWQA) objectives, yet the river was a source of toxic metals and organic chemicals to Lake Ontario (DOE and MOE, 1981). The main contaminants were DDT, PCBs, mirex and mercury. Most organic chemicals were present at concentrations below the minimum detection level in water, which are usually less than the GLWQA objectives. In 1980, PCBs, alpha-BHC and lindane; and alpha and gamma-chlordane, HCB, dieldrin, heptachlor epoxide, and p,p'-DDE were observed in 80% of samples of ambient waters collected over a 10 day period from the mouth of the Niagara River (Kuntz, 1983).

The partitioning of organic chemicals between aqueous and particulate fractions varies considerably with the location in the river and with time. Most of the organic chemicals are in the aqueous phase and the river has a low concentration of suspended solids (5 to 10 mg/L). The collection and analyses of suspended solids from the mouth of the Niagara have been important in establishing long term concentration trends. However, Kuntz and Warry (1983) found that only 40% of the loadings of p,p'-DDE, mirex and PCBs (all extremely hydrophobic organic chemicals) were in the particulate phase. The proportions of other toxic organics were significantly less.

The general pattern of toxic chemical concentrations in the Niagara River above Niagara Falls results primarily from sources on the U.S. side of the River (IJC, 1987b). The presence of compounds such as dioxins and furans, which are known to be present in waste disposal sites, implies that active leaching is occurring to the Niagara River. This conclusion was reached by the NRTC (1984) and from results showing that specific compounds associated with specific waste disposal sites can be found in Lake Ontario sediments (Kaminsky *et al.*, 1983).

Between 1984 and 1987, Environment Canada collected whole water samples from NOTL and Fort Erie for metal analyses. The mean concentrations and ranges for lead, cadmium and arsenic are shown in Table 13. In 1981, the highest levels of lead in water were 2, 3 and 5 ppb (Kuntz, 1984b). These were found just downstream of Buffalo. Between 1975 and 1983, the 12-month moving average of total lead concentrations decreased and is equivalent to loading reductions of from some 430 tonnes/annum in 1975 down to some 200 tonnes/annum in 1983 (Kuntz, 1988b). Between 1979 and 1980, Kauss (1983) reported that mean mercury concentration in the Tonawanda Channel was 100 ppt, compared to 60 ppt in the Chippawa Channel. Mercury concentrations (MOE and DOE, 1981) varied from 60 to 110 ppt in waters of the upper Niagara River. In 1986, mercury was not detected at NOTL or at Fort Erie. In 1982 to 1983, the analytical detection limit for cadmium was 10 ppb which is above the GLWQA objective of 2 ppb (Kuntz, 1984a). In 1985, the cadmium concentrations at NOTL and Fort Erie were less than the minimum detection level of 2 ppb at 1.5 m depths. During 1980, arsenic concentrations in the upper Niagara River were 1 ppb or less but 1 ppb was the minimum detection level.

The database on organic chemicals in water from the Niagara River is extensive because of the focus on the river is a source of contaminants to Lake Ontario. Concentrations of organic chemicals in the Niagara River are shown in Table 12. The 1978 GLWQA objectives have been exceeded in less than 10% of the water sample for total DDT endrin heptachlor/heptachlor epoxide, and endosulphan (DOE and MOE, 1981). Most concentrations were less than 1 or 5 ppt depending on the minimum detection level of the chemical. Most PCB concentrations were less than the minimum detection level of 20 ppt. In 1979, the highest values recorded were 80 ppt for total PCBs; 20 ppt for dieldrin, 7 ppt for alpha-BHC, 1 ppt for lindane, 5 ppt for total DDT and 15 ppt for HCB (MOE and DOE, 1980). Most of these concentrations were from the U.S. side of the upper Niagara River.

Kuntz (1984b) found that between 1975 and 1982 concentrations of total DDT were 1-2 times greater at NOTL than at Fort Erie. El-Shaarawi *et al.* (1985) reported there was a significant difference in mean concentrations between Fort Erie and at NOTL for sixteen toxic chemicals. These chemicals included PCBs, alpha-BHC, mirex, and some chlorobenzenes, including HCB, in whole water. Concentrations of lindane and p,p'-DDE in the aqueous phase and mercury in the suspended phase also increased. McCrea *et al.* (1985) found that alpha-BHC, lindane and dieldrin, and to a lesser extent p,p'-TDE, were mainly in the aqueous phases.

Between 1981 and 1983, weekly water samples from Niagara-on-the-Lake were analyzed by Oliver and Nicol (1984) for several organic compounds and isomers. The distribution of the concentrations of alpha-BHC, total PCBs, 1,2,3,4-tetrachlorobenzene, and HCB, show that maximum concentrations occurred as short-lived (one sample) peaks (Figure 12). The peak concentrations were as follows: 50 ppt alpha-BHC, 34 ppt total PCBs, 36 ppt 1,2,3,4-Tetrachlorobenzene and 30 ppt HCB, but these occurred only on rare occasions. Normally, the concentrations were far less. Concentrations of alpha-BHC and total PCBs varied seasonally more than those for HCB and 1,2,3,4-tetrachlorobenzene. Oliver and Nicol (1984) attributed this to the influence of non-point sources rather than point sources. This problem of short term fluctuations in chemical concentrations in the Niagara River has recently been resolved by installing a continuous extraction system. Oliver and Nicol (1982) found that HCB concentrations in the water above Niagara Falls were near or below the minimum detection level of 0.02 ppt. They found higher concentrations of 1 ppt and 17 ppt near a chemical outfall and a waste disposal site, respectively. In 1982, chlorobenzenes, alpha-BHC and lindane were detected in the plume from the Niagara River in Lake Ontario (Fox and Carey, 1986). In 1979-80, Kauss (1983) found higher concentrations of alpha-BHC and lindane in the Tonawanda Channel than in the rest of the river. In 1986, Stevens and Neilson (in press) found that concentrations of chlorobenzenes, (except for HCB) increased between the outlet of Lake Erie and the Niagara River plume.

Between 1975 and 1982, mirex was observed at levels of 0.0005-0.0075 ppt in the aqueous fraction of 6 of 22 samples (Kuntz, 1984b). El-Shaarawi *et al.* (1985) stated that between 1978 and 1984 there was a significant difference between concentrations of mirex in the combined suspended sediment and aqueous phases at NOTL and Fort Erie. Waste dumps on the U.S. side of the Niagara River could contain large amounts of dioxins produced as by-products of chemical manufacturing (Hallett, 1985). In 200 litre samples taken in tandem 6 m offshore, upstream, opposite and downstream of the 'S' area landfill (Figure 11), isomers of penta-, hexa-, hepta-, and octa-chlorodioxins and dibenzofurans, including isomers of 2,3,7,8,9-pentachlorodioxin and dibenzofuran were detected at concentrations in the order of 0.01 ppt (Hallett, 1985). Residues of 2,3,7,8-TCDD and 2,4,5-trichlorophenol were not detected.

In the late 1970s, suspended solids collected at the mouth of the Niagara River were analyzed to determine trends in loadings of toxic metals to Lake Ontario. In the 1980s, these particulates were also analyzed for toxic organic chemicals. A summary of the chemical concentrations in suspended sediments is shown in Tables 12 and 13. In 1981, a comparison of chemical analyses of suspended sediments from NOTL and from Thunder Bay in Lake Erie showed that many of the chemicals detected at NOTL were not detected in samples from Thunder Bay (DOE and MOE, 1980). However, the process of calculating mean values and loadings is difficult. Wind generated resuspension in Lake Erie can alter the suspended load of the Niagara River by 100%. This has major effects on the partitioning of chemicals between suspended solids and the aqueous phase. McCrea *et al.* (1985) noted that PCB concentrations in suspended solids were lower when the concentrations of suspended solids were higher because of sediment input from Lake Erie. Thus, the partitioning between aqueous and suspended solids phases varies for different organic chemicals and at different locations (NRTC, 1984).

In the late 1970s, lead concentrations were somewhat higher in the upper river perhaps because the method of sampling was intended to detect sources (DOE and MOE, 1981). Mercury concentrations in suspended solids were consistently 3 to 4 times higher in the lower Niagara River compared to the upper Niagara River (Kuntz, 1984b). The distribution of mercury and arsenic in the suspended solids in the river showed that the former increases downstream in concentration, whereas arsenic appears to be relatively evenly distributed (Kuntz, 1984b). The highest concentration of mercury in 1981 was 450 ppb (ng/g) and for arsenic it was 15 ppm (mg/kg).

In 1981, the distributions of toxic organic chemicals in suspended solids showed two patterns (Figure 13) (Kuntz, 1984b). DDT and dieldrin had relatively constant concentrations throughout the river. However, concentrations of PCBs, mirex and HCB were higher in the lower river than in the upper river. The maximum concentration for total DDT, dieldrin, HCB, mirex and total PCBs in suspended solids were 60 ppb, 175 ppb, 3 ppb and 800 ppb, respectively. There are considerable variations with location and time. In 1980, Oliver and Nicol (1982) detected chlorobenzene congeners in suspended sediments at NOTL. The mean concentrations (n = 28) were as follows: 1,2-di 148 ppb, 1,4-di 180 ppb, 1,3-di 95 ppb, 1,3,5,-tri 20 ppb, 1,2,4-tri 61 ppb, 1,2,3-tri 19 ppb, 1,2,4,5-tetra 28 ppb, 1,2,3,4-tetra 71 ppb, penta 58 ppb, hexa 94 ppb. The source of the particulate-associated mirex detected in samples from 1979 and 1980 was considered to be leakage or overflow from storage facilities downstream of Grand Island (Warry and Chan, 1981). Both PCDDs and PCDFs are strongly associated with suspended solids. The higher chlorinated congeners predominated.

Concentrations of organic chemicals in suspended solids collected from the mouth of the Niagara River did not show any distinct trends over the period of measurement (DOE and MOE, 1981; Kuntz, 1983). Lake Erie is not the major source of PCBs, chlorobenzenes and mirex to Lake Ontario because concentrations of these chemicals in Lake Erie bottom sediments are ten times less for PCBs, undetectable for mirex and twenty times lower for hchlorobenzenes than the suspended solids concentrations at Niagara-on-the-Lake (Kuntz and Warry, 1983). Fox *et al.* (1983) reached similar conclusions for these chemicals and HCBD.

2.6.2 Bottom Sediments

The Niagara River has an extremely high discharge rate, about 6,000 m^3/s.

Above the falls there are some areas of nearshore sediment accumulation, at least on a temporary basis. The bottom of the river is either scoured glaciolacustrine sediments or bedrock with very little deposition of unconsolidated recent sediments (NRTC, 1984). Most of the data that follow are based on sampling conducted very close to the shore or near the mouths of tributaries. Thus, although they are sediment data, they do not represent a bottom sediment survey of the type discussed for the depositional basins of the open Great Lakes. The concentrations are more representative of the relative sources to each side of the river. Some of these nearshore samples are highly contaminated. Concentrations of pesticides were generally the highest in samples from the Black Rock Canal, the Wheatfield-Upper River segment, the Buffalo River and the Tonawanda-North Tonawanda and lower river segments (NRTC, 1984). There are considerable variations in the concentrations of individual chemicals, but overall there are higher concentrations in the Buffalo River, Tonawanda-North Tonawanda and Wheatfield-Upper River segments; medium levels in the Lake Erie, Black Rock Canal and Lower River segments; low levels in the Bird Island-Riverside, Fort Erie and Chippawa segments. Cores analyzed by Czuczwa and Hites (1986) indicated that there has been a considerable increase in inputs of total PCDDs and PCDFs since approximately 1940 (Figure 6).

2.7 LAKE ONTARIO

Lake Ontario is the fifth largest of the Great Lakes and has a surface area of 19,000 km^2. Its volume is 1,640 km^3. It is the fifth largest of the Great Lakes but the eleventh largest in the world. With a maximum depth of 244 metres, it is the second deepest of the Great Lakes. Its retention time is approximately 8 years. The largest inflow is the Niagara River (5,700 m^3/s). The other main tributaries are (in decreasing order) the Oswego, Trent, Black and Genesee Rivers. The lake's discharge rate is approximately 7,700 m^3/s via the St. Lawrence River. Circulation in the southern section of Lake Ontario is to the east. The flow then turns north and travels west across the middle of the lake. South of Toronto, the current turns north and then east along the north shore. In the southwest, there is a counterclockwise circulation pattern. The Niagara River plume usually splits as it enters the lake with a smaller section joining the southwest counterclockwise circulation pattern and a larger section joining the easterly current along the south shore of the lake.

Lake Ontario has been contaminated for many years by industrial, agricultural and municipal sources. The highest contaminant levels are in industrialized harbours and embayments. Some of the main contaminants that have been investigated in Lake Ontario are mercury, mirex, PCBs, and chlorobenzenes. Lake Ontario is the receiving water for the largest volume of persistent toxic substances is urban runoff in Canada (Marsalek and Schroeter, 1984). The main industrial centres are Toronto, Hamilton, and Rochester and other important ports are Kingston and Oswego. Seven areas, four in Canada, and the Niagara River, have been designated as Areas of Concern by the International Joint Commission.

2.7.1 Water and Suspended Solids

Metal concentrations in Lake Ontario water (Table 15) are less than those in Lakes Erie and Michigan, but higher than those in Lakes Huron and Superior (Rossmann and Barres 1988). Concentrations of lead in the waters of Lake Ontario are low and uniform although there is a small zone with higher concentrations at the extreme west end of the lake (Schmidt and Andren 1984; Neilson 1983). Lake Ontario has significantly less total and dissolved lead than Lake Erie and significantly less dissolved lead than Lake Michigan (Rossmann and Barres, 1988). Mercury levels in Lake Ontario water are low (Table 15). Levels of total mercury in Lake Ontario were significantly less than those in Lakes Erie and Michigan, while levels of dissolved mercury were significantly less than those in Lake Michigan (Rossmann and Barres, 1988). In the late 1960s, Lake Ontario had the highest arsenic concentrations of all the Great Lakes with a maximum value of 1,200 ppt (Traversy *et al.*, 1975) (Table 15). Arsenic concentrations in the dissolved phase were at least 60% of the total concentration (Rossmann and Barres, 1988).

The use of DDT was restricted in the early 1970s, but it still enters the lake via atmospheric deposition, from the regional use of dicofol which contains traces of DDT and metabolites, and as a photolytic product of methoxychlor which is still used in the Great Lakes basin (Biberhofer and Stevens, 1987). In 1981, McCrea *et al.* (1985) found p,p'-DDT exclusively in the aqueous phase, with an average concentration of just less than 0.04 ppt. In 1986, the mean concentration of p,p'-DDE in Lake Ontario (Table 15) was the same as in Lake Erie and about twice the concentration in Lake Huron.

In 1981, all of the dieldrin in Lake Ontario was in the aqueous phase and the concentration was just less than 0.04 ppt (McCrea *et al.*, 1985). In 1983, Biberhofer and Stevens (1987) reported that the highest levels of dieldrin were in the mid-lake area rather than at nearshore stations. The average concentration of dieldrin in 1986 was similar to that in Lakes Erie, Huron and Superior and indicated that the inputs were historical, atmospheric or from resuspension of contaminated sediments (Stevens and Neilson, in press). In 1981, McCrea *et al.* (1985) found alpha-BHC and lindane completely in the aqueous phase at concentrations of 9 and 8 ppt, respectively. In 1986, the mean concentration of alpha-BHC was similar to that in Lake Erie, but lower than concentrations in Lakes Huron and Superior (Figure 14). Lindane concentrations were similar throughout the lakes (Stevens and Neilson, in press). The mean concentration of HCB in 1986 was lower than that in Lake Erie and higher than in Lakes Huron and Superior (Stevens and Neilson, in press). Mirex is extremely insoluble and was not detected in the aqueous phase in 1977, 1981 and 1983 (Strachan and Edwards, 1984; McCrea *et al.*, 1985; Biberhofer and Stevens, 1987) or in whole water samples in 1986 (Stevens and Neilson, in press). Mirex was detected in 1982 in water from Oswego Harbour (Mudambi *et al.*, 1983) where concentrations in the dissolved phase ranged from less than the minimum detection level (0.005 ppt) to 0.130 ppt. Strachan and Eisenreich (1988) calculated the whole water concentration of mirex in Lake Ontario to be 0.060 ppt. The mean toxaphene concentration of 0.6 ppt in Lake Ontario was the same as the average for all the Great Lakes for that year (Sullivan and Armstrong, 1985). Strachan and Edwards (1984) reported that there are no data for dioxins in the waters of Lake Ontario. Strachan and Eisenreich (1988) used a value of 3 ppt total water B[a]P concentration for their mass balance calculations. In 1981, the concentration of PCBs in the aqueous phase of Lake Ontario was 0.5 ppt (McCrea *et al.*, 1985). Ninety-one percent of the total PCBs were in the aqueous phase (McCrea *et al.*, 1985). In 1983, the highest total PCB concentration (Table 15) was detected adjacent to Hamilton Harbour (Biberhofer and Stevens, 1987). Concentrations of PCBs in Lakes Ontario and Erie were significantly higher than those in Lakes Huron and Superior. Locations identified as having high PCB concentrations in 1983 were Black River Bay (1.9 ppt) and the Niagara River plume (1.1 ppt) (Biberhofer and Stevens, 1987). In 1986, the central area of the lake had PCB concentrations of 1.5 to 2.5 ppt, higher than values nearer the north and south shores (Stevens and Neilson, in press). In 1986, concentrations of chlorinated benzenes were higher in Lake Ontario waters than in the other Great Lakes. In particular, there were major differences in concentrations of di, tri, and tetra chlorobenzenes between Lake Erie at its inflow to the Niagara River and Lake Ontario to the east of the mouth of the Niagara River (Figure 14)(Steven and Neilson, in press).

Lake Ontario has an extensive nepheloid layer (Sandilands and Mudroch, 1983) at depths greater than 60 m. Oliver and Charlton (1984) and Oliver *et al.* (1987) stated that resuspension occurred, especially during the winter months. Lake Ontario is unstratified in the winter and frequent violent storms can penetrate the depths of the lake. Oliver and Charlton (1984) found that given the amount of particulate matter available, the adsorption was low compared to theoretical partition coefficients and that concentrations of organic chemicals were generally higher in the suspended sediment fraction at deeper depths, indicating resuspension of bottom surface sediments. In 1981, Sandilands and Mudroch (1983) found that the suspended particulate concentrations of lead were similar to the concentrations in surface bottom sediment at the same locations.

Data on particulate metal concentrations are shown in Table 15. In 1978 and 1985, most of the lead in Lake Ontario water (approximately two-thirds) was in the particulate fraction (Nriagu *et al.*, 1980; Rossmann and Barres, 1988). In 1981, Sandilands and Mudroch (1983) found that the suspended particulate concentrations of mercury were less than the surface sediment concentrations at the same locations. Nriagu *et al.* (1980) reported higher particulate concentrations of cadmium in nearshore, than offshore waters. When metal levels in each of the Great Lakes were compared (Rossmann and Barres, 1988), Lake Ontario was found to have significantly higher particulate cadmium concentrations than Lakes Superior, Michigan and Huron. Generally, the concentration of particulate cadmium in Lake Ontario decreases from west to east because of sedimentation (Lum, 1987).

In 1981, Sandilands and Mudroch (1983) found that the concentrations of arsenic in suspended solids were less than the surface sediment concentrations at the same locations.

In 1981, all of the p,p'-DDT, 60% of p,p'-DDE, and all of the dieldrin were in the aqueous phase in Lake Ontario (McCrea *et al.*, 1985). Among all the chlorobenzenes, HCB has the greatest tendency to become associated with suspended sediments and most of the HCBs in Lake Ontario are in the bottom sediments (Oliver, 1984). Where mirex was found in the lake, it was almost exclusively in the particulate phase (McCrea *et al.*, 1985). In Lake Ontario surface water, 91% of the PCBs were in the dissolved phase (McCrea *et al.*, 1985). Concentrations of toxaphene and B[a]P in Lake Ontario were calculated by Strachan and Eisenreich (1988). No information was found on dioxins/furans in the particulate phase. McCrea *et al.* (1985) reported that alpha-BHC and lindane were almost exclusively in the aqueous phase.

2.7.2 Bottom Sediments

There are four sedimentation basins in Lake Ontario, named from west to east, Niagara, Mississauga, Rochester and Kingston. The major source of suspended sediment to the lake is the Niagara River. At the mouth of the river, sedimentation occurs off the Niagara Bar.

Concentrations of toxic chemicals in Lake Ontario bottom sediments are summarised in Table 16. Background levels of lead in Lake Ontario bottom sediments are between 18 and 32 ppm. (Mudroch *et al.*, 1985). In 1968, surface sediments were enriched with lead approximately six times above background levels (Thomas and Mudroch, 1979). High concentrations of over 150 ppm conformed to the depositional basins indicating diffuse, rather than point sources (Thomas *et al.*, 1988). Levels of lead in the bottom sediments of the depositional basins of Lake Ontario were significantly higher than those in Lakes Huron and Superior, and higher than those in Lakes Erie (Hodson *et al.*, 1984). In a review of 1974-84 data, Mudroch *et al.* (1988) calculated that the range of lead concentrations reported for the depositional zones in Lakes Ontario and Erie were almost identical. Also, the range of concentrations completely enclosed (with much higher maximum values) those of Lakes Huron, Michigan and Superior. However, they noted that comparisons of concentrations should be treated cautiously because different sampling techniques were used. Background levels of mercury in sediments in depositional zones of Lake Ontario are 30-90 ppb (IJC, 1987b). Background concentrations in the Niagara and Rochester Basins are more than twice those in the Mississauga Basin (IJC, 1987b). The major anthropogenic source of mercury to Lake Ontario is the Niagara River (Thomas, 1972). Because of the effect of the lake currents on the Niagara River plume, the highest concentrations of mercury were found in sediments along the south shore and in an area to the northwest of the river mouth (Figure 3). Eadie *et al.* (1983) suggested that these may be significant local sources of mercury as well as the Niagara River. The range of background levels of cadmium in Lake Ontario is 0.9-3.7 ppm (Mudroch *et al.*, 1985). Concentrations of cadmium in bottom sediments have increased. In 1968, there were many areas with concentrations greater than 6 ppm cadmium in bottom sediments from both depositional and non-depositional areas (Thomas and Mudroch, 1979). In 1970 and 1971, cadmium levels were still increasing in the depositional basin sediments (Kemp and Thomas, 1976a). Lake Ontario has the highest concentrations of cadmium in sediments in the Great Lakes (Lum, 1987), approximately twice those in Lakes Michigan and Erie. Generally, cadmium concentrations are higher in non-depositional zones and embayments (maximum levels of 18.6, 20.6 and 22.0 ppm, respectively) than in the depositional zones (maximum level of 6.2 ppm) (Mudroch *et al.*, 1985). Background levels of arsenic in Lake Ontario are not available. Mudroch *et al.* (1985) reported that surface sediment levels in depositional and non-depositional zones from the late 1960s and the early 1980s were 0.2-17.0 and 0.2-24.0 ppm, respectively.

In 1968, Frank *et al.* (1979a) found total DDT and dieldrin was mainly in the surface bottom sediments of the depositional basins of the lake (Table 16). In 1981, the highest concentrations of DDT were found in bottom sediments along the western shore of the Kingston Basin (Stevens, 1987). In 1980, Oliver and Nicol (1982) reported chlorobenzene concentrations in Lake Ontario sediments (Table 16) to be much higher than in Lakes Superior, Huron and Erie (10-38 ppb). Also, the higher chlorinated chlorobenzenes, associated with industrial activity, were more common in Lake Ontario than in the other lakes. In a 1981 survey of surficial sediments, Oliver *et al.* (1987) found mean concentrations of HCB for the Niagara, Mississauga, Rochester and Kingston Basins to be 110, 130, 100, and 14 ppb, respectively. In 1968, Holdrinet *et al.* (1978) observed areas of sediment with mirex concentrations above 10 ppb extending from the Niagara and Oswego Rivers (Figure 15). The mean concentration of mirex in surficial sediments in 1968 was 7.5 ppb (Holdrinet *et al.*, 1978). By 1977, large areas of the lake had concentrations of mirex over 20 ppb (Thomas *et al.*, 1988). The mean concentration in 1981 was 33 ppb (Oliver *et al.*, 1987) based on fewer samples, all of which were from the depositional basins. Pickett and Dossett (1979) predicted that by 1989 the highest concentrations of mirex would be in two plumes: at the mouth of the Niagara River and along the southern shore and adjacent to the mouth of the Oswego River, respectively. Eadie *et al.* (1983) predicted that the plume would move from the southern shore to the south-eastern shore and then to the Niagara and Rochester basins. The predictions made by Eadie *et al.* (1983) are closer to the results reported by Oliver *et al.*, (1987), who stated that by 1981 mirex was becoming more evenly distributed in the sedimentary basins. No data on concentrations of toxaphene have been reported for Lake Ontario sediments (Strachan and Edwards, 1984). Onuska *et al.* (1983), calculated that PAHs introduced to the lake from the Niagara River generally moved to the east.

The congener profiles of PCDDs and PCDFs in Lake Ontario sediments were different from the other Great Lakes because of the high concentration of OCDF present (Czuczwa and Hites, 1986). The presence of OCDF indicates a local source. This could be from the production of HCB and pentachlorophenol (PCP). HCDF, HpCDF, OCDF, and 2,3 7,8-TCDD were all detected in sediments offshore from the mouth of the Niagara River in the early 1980s (Onuska *et al.*, 1983; Kaminsky *et al.*, 1983). The maximum concentration of 2,3,7,8-TCDD in bottom sediment was 13 ppt (Onuska *et al.*, 1983).

In 1968, mean PCB concentration was generally higher (85 ppb) in the depositional than non-depositional (28 ppb) basins. The mean value for the whole lake was 58 ppb (n=216). A plume of >200 ppb PCBs extended from the mouth of the Niagara River. Minor plumes indicated other local sources along the north and south shores (Frank *et al.*, 1979a; Thomas and Frank, 1983) (Figure 4). The mean PCB concentrations in 1981 (Oliver *et al.*, 1987) were considerably higher (570 ppb) than those for 1968 (58 ppb). This is probably because of improved extraction and analytical techniques.

In 1970 and 1971 sediment cores from all five stations in Lake Ontario showed surface enrichment with anthropogenic mercury, lead, zinc, cadmium and copper (Kemp and Thomas, 1976a). In 1981, two cores taken from the eastern end of the lake were shown to have subsurface maximum concentrations of mercury (Figure 16) and lead. However, surface levels (120-150 ppm) were still considerably higher than background concentrations (Eadie *et al.*, 1983). The cores indicated that the average lead flux to Lake Ontario increased by 680% from the early 1800s to the time of maximum lead usage in the mid 1970s (Eadie *et al.*, 1983). Concentrations of lead in surface sediment were still high in the early 1980s: they were between 100 and 200 ppm near the Niagara River mouth (Mudroch, 1983). Changes in concentrations of mercury are the most dramatic of any in metal levels (Mudroch, 1983; Mudroch *et al.*, 1988). Mercury concentrations increased rapidly in a core taken in 1970 between the turn of the century and the early 1940s. Between then and 1970, concentrations increased at a slower rate and were in the range of 1-1.5 ppm (Thomas, 1972). Similar increases were seen in cores sampled in 1970 and 1971 from the depositional basins. Higher surface concentrations were reported for the Niagara and Rochester Basins than for the Mississauga Basin. The surface sediment concentration range for the three basins was 2.6-3.9 ppm (Kemp *et al.*, 1974). Cores taken in 1981, from both ends of the lake showed a reversal of this trend (Eadie *et al.*, 1983; Mudroch, 1983) (Figure 16). Immediately adjacent to the mouth of the Niagara River, maximum subsurface mercury concentrations ranged from 4 to 7 ppm. Surface levels were approximately 1 ppm. Ranges in the eastern cores were slightly lower. This site now has surface sediment concentrations less than those of surficial sediments farther out in the lake although it used to have the highest surficial concentration. The more contaminated sediments are still within mixing depths for benthic organism, whereas the previous highest concentrations near the Niagara River mouth are now below this (Allan, 1986).

In 1976, the highest concentrations of total DDT in cores were in the surface sediments. DDT first appeared in sediments in the late 1950s (Frank *et al.*, 1979a). In a 1982 core, peak levels of total DDT were seen in the late 1950s to the early 1960s. This agrees with DDT patterns (Oliver *et al.*, 1987).

Oliver and Nicol's (1982) core showed that concentrations of chlorobenzenes in sediment began to increase in the early 1940s and began to decrease in the late 1960s (Figure 16). This corresponds to the use of chlorobenzenes in the production of phenols. There was little, if any, change in the proportions of the various chlorobenzenes in this core. Cores analyzed by Onuska *et al.*, (1983) also showed that there may have been a decrease in chlorobenzene loading from the Niagara River during the 1970s. HCBD and OCS concentrations in cores also peaked (160 ppb and 550 ppb, respectively) in the 1960s and 1970s, respectively. Concentrations of HCBD were low prior to the late 1950s and after the early 1970s, but there were high concentrations during the 1960s (Durham and Oliver, 1983). Concentrations of mirex in sediment cores reflected its production in the Niagara River area (Durham and Oliver, 1983; Eadie *et al.*, 1983) (Figure 16). Because concentrations continued to increase and the area affected got larger after production ceased (in 1976), remobilization of contaminated sediments from the Niagara River has been suspected (Thomas *et al.*, 1988). Durham and Oliver (1983) found the highest concentrations of PCBs were at sediment depths corresponding to the early 1960s (Figure 16). Concentrations of PAHs in sediment cores were 100 times higher in surface layers than in deeper sediments, indicating extensive loading in the late 1970s.

2.8 ST. LAWRENCE RIVER

The St. Lawrence River drains Lake Ontario and the Great Lakes. It discharges to the Atlantic Ocean. Its discharge rate is approximately 7,700 m^3/s. The mean concentration of suspended solids in the river at its source in Lake Ontario is 1.3 mg/L (mean of four years of data). The international section of the river included in the Great Lakes Water Quality Agreement stretches from Lake Ontario to the Province of Quebec and thus does not include Lake St. Francis. Major industries are located on the Canadian and shores of the river, just upstream from Quebec. They include a major foundry, automobile plant and two large aluminium plants. In the Cornwall area, a chlor-alkali plant used to discharge mercury and this resulted in high levels of mercury in downstream bottom sediments. A former tetraethyl lead plant located near Maitland used to be a source of alkyl leads to the river.

2.8.1 Water and Suspended Solids

In 1977, the mean concentrations of the metals discussed here were 0.50 to 1.01 ppb for lead; ND - 0.004 ppb for mercury; less than the minimum detection level for cadmium; and 0.55 - 0.73 ppb for arsenic between Kingston and Cornwall (Chan, 1980). These results were based on unfiltered water. Between 1977 and 1983, water samples from the St. Lawrence outflow from Lake Ontario were routinely analyzed for inorganic chemicals (Sylvestre *et al.*, 1987). When means were calculated, values less than the minimum detection level were taken as equal to it. Between 1977 and 1983, the mean concentration of lead was 1.2 ppb (n= 341). There were no data on mercury, cadmium or arsenic. Between 1979 and 1982, filtered water samples showed that mercury concentrations at Cornwall - Massena were less than 0.2 ppb. Lum and Kaiser (1986) reported dissolved cadmium concentrations of between 3 and 23 ppt (mean = 10pp: n=11).

In 1977, lindane and alpha-BHC, were detected in water from the St. Lawrence River between Kingston and Cornwall at concentrations from 3 to 7 ppt and 3 to 8 ppt respectively (Chan, 1980). In 1982, water and suspended sediments collected from the source of the St. Lawrence River near Wolfe Island began to be analyzed routinely for toxic organic chemicals (Sylvestre, 1987). Samples were analyzed for PCBs, PAHs, chlorobenzenes and organochlorine pesticides. In whole water, only 3 of the 18 organochlorine pesticides measured were detected in more than 40% of the samples. Between 1982 and 1984, mean concentrations were 5.8 ppt alpha-BHC, 1.0 ppt lindane, and 0.4 ppt dieldrin (Sylvestre, 1987). The results for <40% detection were not considered meaningful to calculate means using the minimum detection level as the lower value. When larger volume samples (200 L versus 2 L) were extracted in 1983, other chemicals were detected above the more sensitive minimum detection level. The results from this 1983 study were 4.8 ppt alpha-BHC, 1.2 ppt lindane, 0.54 ppt dieldrin (all similar to the above), 0.17 ppt total DDT and 0.43 ppt total PCBs. Concentrations of mirex were less than the minimum detection level. The concentration of p,p'-DDT was 0.065 ppt in the aqueous phase and 0.02 ppt in the suspended solids, while PCBs were present at 2.0 ppt in the aqueous phase and at less than 0.1 ppt in suspended solids. In 1977, PCBs were detected in water at the mouth of the Grass River at concentrations of 60 and 180 ppt.

PCBs concentrations of 20 to 70 ppt in water and up to 660 ppb in suspended solids were measured at the mouth of the Grass River between 1979 and 1982 (MOE, 1988a).

Lum and Kaiser (1986) reported particulate cadmium concentrations of 1.0 to 3.8 ppm (mean = 2.1 ppm; n = 12) for 1985. Between Cornwall and Massena, suspended solids had mercury concentrations of up to 2.4 ppt in 1979-82. Merriman (1987) reported concentration ranges in suspended solids of <1-2 ppb alpha-BHC, <1 ppb for lindane, <1-14 ppb for dieldrin, <1-16 ppb for p,p'-DDT, 7-18 ppb for p,p'-DDE, 11-34 ppb for total DDT, <1 to 6 ppb for mirex, 1-27 ppb for HCB, and 30 to 126 ppb for total chlorobenzenes between Kingston and Cornwall in 1981. The spatial distributions of total DDT, total PCBs and mirex are shown in Figure 17. Between 1982 and 1984, concentrations of lindane were less than the minimum detection level of 4 ppb, while alpha-BHC and dieldrin were detected in more than 40% of the samples at mean concentrations of 6 ppb and 9 ppb, respectively, in suspended solids collected from Wolfe Island (Sylvestre, 1987). PCBs were detected in 93% of the samples, at a mean value of 162 ppb. Total DDT was found in 90% of the samples at a mean concentration of 18 ppb. Mirex was detected in 33% of the samples and concentrations ranged from less than the minimum detection level of 4 ppb to a maximum of 27 ppb. A mean concentration could not be calculated for mirex because the frequency of detection was only 33%, however, the mean of the concentrations above the minimum detection level was 9.8 ppb (n= 26). In 1981, mirex concentrations ranged from less than the minimum detection level to 6 ppb (Figure 17). The occurrence of some chlorinated benzene congeners in suspended solids was >50%. The mean concentrations (maximum values are in brackets,) were 32 ppb (131) 1, 2, 4-tri, 14 ppb (95) 1, 2, 3, 4-tetra, 11 ppb (56) penta, and 13 ppb (54) hexa chlorobenzene (Sylvestre, 1987). Most PAHs were not detected in the suspended solids at a minimum detection level of 50 ppb. The few exceptions could be the result of interference in the analyses.

2.8.2 Bottom Sediments

In 1975, Kuntz (1988a) collected bottom sediments between Kingston and Cornwall and Cape Vincent and Massena on the Canadian and U.S.

sides of the St. Lawrence River. Lead concentrations ranged from less than the minimum detection level of 50 ppm up to 190 ppm. Mercury concentrations were usually well below 0.3 ppm, except for a site immediately downstream of Cornwall where the concentration was 4.9 ppm. Concentrations of cadmium were generally less than minimum level of 10 ppm. Five of fifty-six samples contained detectable concentrations of cadmium and the maximum was 14 ppm. This was from a site just downstream of the Grass River. Concentrations of arsenic ranged up to 7.6 ppm on the Canadian side and 8.0 ppm on the U.S. side of the river.

In 1975, p,p'-DDT was not detected in any of the 57 samples analyzed (Kuntz, 1988a). Several samples contained p,p'-TDE at concentrations above the minimum detection level. These were in the range of 3 to 11 ppb, and were in samples from the Gananoque-Rockport area. Concentrations of p,p'-DDE were usually less than the minimum detection limit of 1 ppb and the maximum concentration was 90 ppb. In 1981, the highest concentration of total DDT was 56 ppb. This was in a sample collected from just off Kingston (Merriman, 1987) (Figure 17). The maximum HCB concentration detected in 1981 was 13 ppb for the seven sites sampled (Merriman, 1987) and occurred in a sample in the DuPont outfall zone near Maitland (MOE, 1988b). The bottom sediment survey of 1975 did not detect mirex in any of the samples at a minimum detection level of 1 ppb (Kuntz, 1988a). In 1981, Merriman (1987) detected mirex at only one site near Kingston at 9 ppb.

In 1975, Kuntz (1988a) found levels of PCBs above 50 ppb at 10 of 57 stations. The highest value was 1.5 ppm downstream of the Grass River. In 1981, the highest bottom sediment PCB concentration was 8.74 ppm at the mouth of the Grass River (Merriman, 1987). Total chlorobenzenes were found at low concentrations of 8-9 ppb in bottom sediments (Merriman, 1987). The maximum concentration was 50 ppb.

3. CONCLUSIONS

The most heavily contaminated of the Great Lakes are Lakes Ontario, Michigan and Erie, based on an assessment as concentrations of contaminants in abiotic aquatic media. Lake Superior is the least contaminated. Lake Huron is relatively uncontaminated, except for some local areas. Generally, the concentrations of toxic chemicals in the Great Lakes are decreasing. Concentrations of some chemicals are still increasing especially along the St. Clair-Detroit River corridor and in the Niagara River.

There are higher concentrations of contaminants in the water of the nearshore areas and there are higher concentrations in sediments in the depositional basins, harbours and deltas. In the connecting channels, higher concentrations of contaminants are usually found along the shore downstream from sources. There are also unique patterns in each lake and channel. In Lake Superior, concentrations of organics are higher in the northern part of lake than in the southern part. High levels of lead, mercury and cadmium have been reported in some of the bays and harbours. All of Rossmann's metal concentrations in Lake Superior were below the GLWQA objectives. The highest levels of toxic chemicals in the St. Marys River were generally found along the Canadian shore. In Lake Michigan, concentrations of toxic organic chemicals are usually higher in the southern section of the lake and Green Bay. PCB concentrations are highest in the sediments of the southwest part of the lake. Saginaw and Georgian Bays are major sources of toxic chemicals to Lake Huron. In the St. Clair River, high concentrations of toxic chemical are confined primarily to a 100 metre wide area along the Ontario shore near Sarnia's chemical industrial area, for example, PCBs, volatile hydrocarbons, lead and mercury. Spills are an important problem. Increasing water and/or sediment concentrations have been reported for lead, mercury, HCB, HCBD, OCS, OCB and PAHs over the course of the river. Levels above the GLWQA objectives have been found for lead, HCB and HCBD, and above dredging guidelines for OCS, PAHs and PCBs. In Lake St. Clair, the highest concentrations of PCBs have been reported on the western side. High levels of contaminants have been found in sediments from the central depositional basin and at the outlet. In the Detroit River the majority of sources are along the U.S. shore and along the Rouge River. Chemical concentrations of cadmium, PCBs, chlorobenzenes, lindane, industrial volatile halocarbon and PAHs in water and/or sediment have been reported to increase along the river. Levels of lead, mercury, cadmium, arsenic, PCBs, PAHs, alpha-BHC and lindane have been reported to be above dredging guidelines. The western basin of Lake Erie is the most affected by toxic chemicals mainly because of inputs from the Detroit River; for example, PCBs and industrial halocarbons in water; PCBs, HCB, HCBD, and PAHs in sediments; and DDT and metabolites, mercury and cadmium in sediments in the 1970s. The main sources of toxic chemicals to the Niagara River are along the U.S. shore. Concentrations of many contaminants are higher in the water and sediments from the Tonawanda Channel than in the Chippawa Channel. Since there is extensive mixing at Niagara Falls, there is no plume. Increases along the course of the river were observed in the late 1970s-1980s for PCBs, alpha-BHC, lindane, chlorobenzenes (sometimes including HCB), HCBD, mirex, p,p'-DDE, mercury, cadmium, arsenic, PAHs and B[a]P. Sources of dioxins and furans have also been found. Concentrations of mercury, arsenic, PCBs, mirex, HCB and HCBD are much lower in the sediments of Lake Erie than in Lake Ontario. Concentrations of DDT and its metabolites have decreased recently between Fort Erie and Niagara-on-the-Lake. The Niagara River has historically been the main source of toxic chemicals to Lake Ontario. These chemicals initially collect in the sediments in a pattern which reflects lake circulation. Eventually, they move into the depositional basins. Along with other dioxins and furans, 2,3,7,8-TCDD has been detected in the sediments offshore from the mouth of the Niagara River.

Temporal trends in concentrations of contaminants have been determined for each of the lakes and channels. In Lake Superior, historic data for concentrations of lead, mercury and cadmium could not be used to determine trends in the water. Arsenic concentrations in whole water have decreased since the 1970s. There has been a dramatic reduction in PCB concentrations in the waters and sediments of Lake Superior since the early and mid 1970s. Lead in sediments had a higher anthropogenic enrichment factor than mercury, cadmium and arsenic. Concentrations of lead and mercury are now decreasing in the surface sediments. Historic data on concentrations of lead, mercury and cadmium in Lake Michigan can not be used to determine trends in the water. Arsenic concentrations in whole water have decreased since the 1970s. Concentrations of lead have decreased in the sediments from high levels in the 1950s and 1960s. Concentrations of cadmium have also decreased from the peak levels in the 1940s and 1960s. Levels of PCBs have decreased from peak levels in the 1960s and 1970s. In Lake Huron, historic data on mercury, cadmium and arsenic in water can not be used to determine trends. Dissolved lead concentrations have decreased in Lake Huron. There are indications that levels of lead, cadmium and DDT in the water of Saginaw Bay have decreased since the 1970s. In cores taken before 1980, there was surface enrichment of lead, mercury, cadmium and arsenic. Mercury levels in bottom sediments have decreased in most parts of the St-Clair River, however, levels are often still above the dredging guideline. Concentrations of HCB, HCBD and PAHs in sediments show that concentrations have decreased slightly over time. For Lake St. Clair, concentrations of PCBs, mercury and DDT decreased in bottom sediments following the restrictions on its use imposed in the early 1970s. The concentrations of HCB and HCBD in the sediments of Lake St. Clair are still increasing or at least not dropping significantly. Generally, levels of mercury have decreased in the bottom sediments of the Detroit River, however, levels are often still above the dredging guideline. In Lake Erie, historic lead data can not be used to determine trends in the water but concentrations of mercury, cadmium and arsenic are decreasing. Concentrations of PCBs may be decreasing in the water of Lake Erie. Cores collected in the early 1970s showed that concentrations of lead, mercury and PCBs from anthropogenic sources increased. More recent cores show that concentrations of lead, arsenic, DDT and its metabolites, dioxins and furans have decreased at the surface. Levels of PCBs may not be decreasing in the sediments. During the 1980s, point source loadings to the Niagara River decreased by over 60% on both sides of the river. Because of changes in analytical methods, water samples from the early 1980s cannot be compared to those of the mid 1980s. Between the mid 1970s and the 1980s, lead loadings from the Niagara River to Lake Ontario fell by half. Peak levels of mercury in the sediments of the delta occurred in the early 1950s. By the end of the 1970s, mercury levels were back to pre 1940 levels. From the late 1960s to the early 1980s, concentrations of mirex and PCBs in surface sediments of Lake Ontario increased; however, this may have been done to improved analytical and sampling techniques because analyses of cores refute this trend. Analyses of cores showed enrichment of lead, mercury, cadmium, DDT, chlorobenzenes, HCBD, OCS, mirex, PCBs and PAHs from anthropogenic sources in bottom sediments, but concentrations are now decreasing or levelling off. In the St. Lawrence River, lead and mercury concentrations in sediments have decreased following the closure of source industries.

The sources of toxic chemicals and the physical characteristics of the lakes and channels influence the relative concentrations of contaminants in each area. The atmosphere is a more important source of most of the critical toxic chemicals to the upper Great Lakes than the lower lakes. The major contributing factors are the large surface areas and drainage basins of the upper lakes. Conversely, the lower lakes receive greater inputs from their main tributaries, industries, municipalities and agriculture than the upper lakes. Concentrations of contaminants, such as dieldrin and toxaphene tend to be similar throughout the Great Lakes. The major sources of these chemicals are atmospheric and/or sediment resuspension. Total suspended matter concentrations in the lake are (from highest to lowest) Lakes Erie, Ontario, Huron and Michigan and Lake Superior. Sedimentation rates are highest in Lake Erie, followed by Lakes Ontario and Michigan, followed by Lakes Huron and Superior. Higher total suspended matter and sedimentation rates reduce bioaccumulation of contaminants and accelerate natural self cleansing of the lakes. Lakes Michigan and Superior have long water residence times so that most of the chemicals introduced into these lakes are not quickly translocated downstream.

There is considerable variation in the concentrations of contaminants in the waters of the Great Lakes. The total concentrations of metals in water are (from highest to lowest) Lakes Michigan, Erie, Ontario, Huron and Superior. Concentrations of metals in Lake Superior are lower than in the other lakes, except for dissolved arsenic in Lake Huron and particulate cadmium in Lake Michigan. Concentrations of metals in Lake Huron are also consistently less than in the other lakes. In the mid 1970s, PCB concentrations in suspended solids of the Detroit River and the Niagara River were the highest in the Great Lakes. In the mid 1980s, Lake Ontario had higher concentrations of toxic organic chemicals in whole water than Lakes Superior, Huron and Erie. The mean concentrations of chlorobenzenes and lindane ranked highest in Lake Ontario. Concentrations of PCBs, p,p'-DDE, chlorobenzenes and alpha-BHC were higher in Lakes Ontario and Erie than in Lakes Superior and Huron. Whole water concentrations of chlorobenzenes, dieldrin and PCBs were similar in Lakes Superior and Huron. Dieldrin, lindane and toxaphene were found to be ubiquitous. Mirex is generally not detected in the waters of the Niagara River and Oswego Harbour (Lake Ontario).

There were also variations in sediment concentrations. In the sediment survey of the late 1960s and early 1970s, concentrations of lead, mercury and cadmium in the lower lakes were higher over greater areas of the lake bottom than in the three upper Great Lakes. Lead enrichment in Lake Superior is less than in the other Great Lakes. Information on arsenic concentrations in Great Lakes sediments is scarce. In 1980, levels of HCB in the sediments were much higher in Lake Ontario than in Lakes Superior, Huron and Erie. PAH concentrations in sediments are about 10 times lower in Lake Superior than the other Great Lakes, reflecting both its remote location and that the atmosphere is the primary source. There has been a recent decrease in the level of B[a]P in Lake Superior and the St. Marys River. Lake Michigan has high concentrations of PAH in the sediments. The main sources of dioxins and furans to the Great Lakes sediments are municipal and industrial combustion of waste containing chlorinated organic chemicals. OCDD and HpCDF predominated. The highest concentrations of OCDD were in Lake Ontario, followed by Lake Erie and Lakes Michigan and Huron. Lake Ontario also had high levels of OCDF, indicating a local source.

The high concentrations of metals in water documented in the past are now thought to reflect sample contamination. The use of special sampling and clean laboratory techniques is now suggesting that dissolved concentrations of lead, cadmium and other metals are much less (in the low ppt range) than previously thought (in the low ppb range). Likewise recent sampling techniques using large volume aqueous phase or continuous flow extraction systems have allowed extremely low concentrations (< 1 ppt) of organic chemicals to be detected in water samples. Historical data on concentrations of organic chemicals in water included a lot of non-detected concentrations or high concentrations which now must be interpreted cautiously.

The data on concentration of toxic chemicals in the water of each of the lakes shows that different contaminants are found in the different lakes. The historical data on metals and organic chemicals indicate that concentrations have decreased over time. However, this conclusion should be viewed in the context of the above comments on data reliability. If the historical values are taken at face value, then concentrations of some chemicals such as lead, cadmium and PCBs have decreased dramatically in some of the lakes. Decreases in concentrations measured in the last few years are probably more accurate. The most recent data on metals and organic chemicals are the most reliable and show that ambient concentrations are much lower than those determined in the past.

Data on contaminants in nearshore areas are scarce. There are data on the connecting channels and the concentrations of chemicals in water in these channels can vary considerably over short periods of time. The same is probably true for nearshore sites, if they are affected by tributaries or effluents from industry or municipalities. More data on the nearshore areas of Canada are being generated for the Remedial Action Plans (RAPs) and for the Ontario Municipal and Industrial Strategy for Abatement (MISA) There is no simple relationship between concentrations of contaminants in raw water and those in drinking water from the Great Lakes. Drinking water intakes are located nearshore, often within a kilometre or less of the shoreline. Wave action or storms can resuspend nearshore sediments, cause an upwelling of deeper lake water or can cause increased sediment loads in small creeks which discharge to the nearshore zone. Each intake is unique because the environmental conditions at each one are different. Drinking water treatment plants are designed to take account of these local factors by filtering the raw water and by removing suspended and colloidal material by flocculation. Thus, human exposure is best assessed by analyses of treated drinking water.

The open water data are a good measure of the total lake contamination and can be used for comparison with information on contaminant level in open lake fish. However, the relationship between the concentrations of chemicals in water and sediments and the concentrations in biota in the lakes is not simple. It is possible that the majority of contaminants are taken up directly by fish from the water and bioconcentrated. However, an alternative hypothesis is that contaminants are primarily bioaccumulated in the food web. The sediments or water surrounding them may be a major source of chemicals for biota which inhabit contaminated sediments or for fish which eat organisms living in such sediments. For some fish it may well be all three, i.e., water, sediments and other biota. The mix will be different for different organisms, at different trophic levels, with different diets and dependent on local contamination.

Until recently, analyses of bottom sediments, and in particular cores of bottom sediments, have been used to detect trends in chemical inputs and concentrations in water in the lakes. Temporal trends for many contaminants indicate that concentrations have decreased, compared to concentrations 10 and 15 years ago. The data suggest that the major influx of contaminants to the Great Lakes aquatic ecosystem took place in the 1960s and 1970s. Dated cores show similar trends for most of the contaminants discussed in this report. Some of these decreases have been dramatic and followed the bans and restrictions on the manufacture and use of contaminants, such as PCB and mirex. Often, the periods of peak input of contaminants occurred several years before they were first detected in lake media. Thus, the overall evidence from the abiotic data is that the maximum inputs of most of these contaminants occurred in the past and that the inputs of such chemicals have decreased.

The purpose of this report was to give an overview of concentrations of contaminants in water and sediments of the Great Lakes over time. However, problems with the historical data on concentrations of contaminants in water make this difficult. There are better data available on sediments because there are many maps of the distribution of contaminants in sediments and there are sediment core data. There are more data on water because concentrations, particularly in the connecting channels, can change rapidly with time.

No new ubiquitous, highly toxic and persistent contaminants have been detected in any of the Great Lakes since 1982. Future control actions will have to take into account non-point sources of the contaminants, especially atmospheric sources, chemicals recycled from contaminated sediments, agricultural, forestry and urban sources, and contaminated groundwater. The sequencing of control actions and remedial programs will rely heavily on accurate assessments of relative source loadings and mass balances for the connecting channels and whole lakes. The next major steps in the continued recovery of the Great Lakes from chemical contamination will result from the implementation of Remedial Action Plans and from the application of load-based controls as part of Lakewide Management Plans.

In the 1978 Great Lakes Water Quality Agreement, Canada and the U.S. agreed to the virtual elimination of all persistent toxics from the Great Lakes with an eventual goal of zero discharge of persistent, toxic organic chemicals. Since 1978, programs have been initiated at many locations, including the Niagara Frontier, the Detroit and St. Clair Rivers, and many Area of Concern to reduce or eliminate inputs of contaminants to the Great Lakes. These and other programs should be expedited so that the goals of virtual elimination and zero discharge can be realized.

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6. APPENDIX

6.1 ACRONYMS

AOC	Area of Concern
CCREM	Canadian Council of Resource and Environment Ministers
DOE	Environment Canada
FE	Fort Erie
GLWQA	Great Lakes Water Quality Agreement
IJC	International Joint Commission
MISA	Municipal-Industrial Strategy for Abatement
MOE	Ontario Ministry of the Environment
NOTL	Niagara-on-the-Lake
NRC	National Research Council
NRTC	Niagara River Toxics Committee
NYDEC	New York Department of Environmental Conservation
RAP	Remedial Action Plan
RSC	Royal Society of Canada
TSM	Total Suspended Matter
UGLCCS	Upper Great Lakes Connecting Channel Study
USEPA	United States Environmental Protection Agency

6.2 CHEMICAL ABBREVIATIONS

*	2,3,7,8-TCDD	2,3,7,8-Tetrachlorodibenzo-p-dioxin
*	2,3,7,8-TCDF	2,3,7,8-Tetrachlorodibenzofuran
	As	Arsenic
*	B(a)P	Benzo(a)pyrene
	BHCs	hexachlorocyclohexanes
	a-BHC	alpha-1,2,3,4,5,6-BHC
	g-BHC	gamma-1,2,3,4,5,6-BHC; use Lindane
	CBs	Chlorobenzenes
	Cd	**Cadmium**
	DCB	Dichlorobenzene
*	DDD (TDE)	Dichlorodiphenyl dichloroethane
*	**DDE**	**Dichlorodiphenyl dichloroethylene**
*	**DDT**	**Dichlorodiphenyl trichloroethane**
*	**Dieldrin**	**use for HEOD**
	Dioxins	**see PCDD**
*	**HCB**	**Hexachlorobenzene**
	HCBD	**Hexachlorobutadiene**
	HCH	use BHC
	HEOD	use Dieldrin
*	**Hg**	**Mercury**
*	**Mirex**	**Dodecachloropentacyclodecane**
	OCS	Octachlorostyrene
	OCDD	Octachlorodibenzo-p-dioxin
	OCDF	Octachlorodibenzofuran
	PAHs	**Polynuclear Aromatic Hydrocarbons**
*	**Pb**	**Lead**
*	**PCBs**	**Polychlorinated Biphenyls**
	PCDD	**Polychlorinated dibenzo-p-dioxin**
	PCDF	**Polychlorinated dibenzofuran**
	PCP	Pentachlorophenols
	PERC	Perchloroethylene; use for Tetrachloroethene
	QCB	Pentachlorobenzene
	TCB	Trichlorobenzene
	TCDD	**use for 2,3,7,8-TCDD**
	TCDF	**use for 2,3,7,8-TCDF**
	TCP	Trichlorophenol
	TeCB	Tetrachlorobenzene
*	**Toxaphene**	**use for Chlorinated Bornane**
	Zn	Zinc

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* = IJC Primary Track Chemicals.
Bold = Main chemicals discussed in this report.

6.3 GLOSSARY

Area of Concern: a geographic area that fails to meet the General or Specific Objectives of the GLWQA Agreement where such failure has caused or is likely to cause impairment of beneficial use of the area's ability to support aquatic life (IJC, 1988)

Bioaccumulation: general term describing a process by which chemical substances are accumulated by aquatic organisms from water directly or through consumption of food containing the chemicals (CCREM, 1987)

Bioassay: test used to evaluate the relative potency of a chemical by comparing its effect on a living organism with the effect of a control, without the test chemical, which is run under identical conditions (CCREM, 1987).

Bioconcentration: a process by which there is a net accumulation of a chemical directly from water into aquatic organisms resulting from simultaneous uptake (e.g., by gill or epithelial tissue) and elimination (CCREM, 1987).

Bioconcentration factor (BCF): a unitless value describing the degree to which a chemical can be concentrated in the tissues of an organism in the aquatic environment. At apparent equilibrium during the uptake phase of a bioconcentration test, the BCF is the concentration of a chemical in one or more tissues of the aquatic organisms divided by the average exposure concentration in the test. (CCREM, 1987)

Biomagnification: result of the processes of bioconcentration and bioaccumulation by which tissue concentrations of bioaccumulated chemicals increase as the chemical passes up through two or more trophic levels. The term implies an efficient transfer of chemicals from food to consumer, so that residue concentrations increase systematically from one trophic level to the next (CCREM, 1987).

Bioturbation: the physical disturbance of sediments by burrowing and other activities of organisms (CCREM, 1987).

Carcinogen: a substance which induces cancer in a living organism (CCREM, 1987).

Congener: a different configuration or mixture of a specific chemical usually having radical groups attached in numerous potential locations (UGLCCS 1989).

Contaminant: a substance foreign to a natural system or present at unnatural concentrations (UGLCCS, 1989).

Detection Limit: The smallest concentration or amount of a substance which can be reported as present with a specified degree of certainty by a definite, complete analytical procedure (CCREM, 1987).

Dioxin: a group of approximately 75 chemicals of the chlorinated dibenzodioxin family, including 2,3,7,8-TCDD which is generally considered the most toxic form (UGLCCS, 1989).

Dredging Guidelines: procedural directions designed to minimize the adverse effects of shoreline and underwater excavation with primary emphasis on the concentrations of toxic materials within the dredge spoils (UGLCCS, 1989).

Effluent: a complex waste material (e.g. liquid industrial discharge or sewage) which may be discharged into the environment (CCREM, 1987).

Great Lakes Water Quality Agreement: a joint agreement between Canada and the U.S. which commits the two countries to develop and implement a plan to restore and maintain the many desirable uses of the waters in the Great Lakes Basin. Originally signed in 1978, the Agreement was amended in 1987 (UGLCCS, 1989).

Guideline (water quality): numerical concentration limit or narrative statement recommended to support and maintain a designated water use (CCREM, 1987).

Half-life: the time require for the concentrations of a substance to diminish to one-half of its original value in a lake or water body (GLWQA, 1978).

Loading: the amount of a substance added per unit of lake area per unit time (CCREM, 1987).

Mass-Balance Approach: a management approach in which the aim is to eliminate accumulation of pollutants what will degrade water quality or have adverse affects on living organisms. This approach requires establishment of a mass-balance budget in which the amounts of contaminants entering the system less the quantities stored, transformed, or degraded within the system must equal amounts leaving the system. Application of this approach depends on quantification of sources and effects of contaminants and mathematical modelling to simulate probable long- term consequences (NRC and RSC, 1985).

Municipal-Industrial Strategy for Abatement: the principal goal of this program is the virtual elimination of toxics discharged from point sources to surface waters in Ontario (UGLCCS, 1989).

Mutagen: any substance or effect which alters genetic characteristics or produces an inheritable change in the genetic material (UGLCCS, 1989).

Nepheloid Layer: regions of turbid bottom water characterized by a maximum in light scattering and particle concentration. Possible sources of nephloid material are eroded shore material, suspended matter brought in a large river, deep sediments eroded by bottom currents, and organic matter settling from surface layers (Chambers and Eadie, 1981; Sandilands and Mudroch, 1983).

Nonpoint source: source of pollution in which pollutants are discharged over a widespread area or from a number of small inputs rather than from distinct, identifiable sources (UGLCCS, 1989).

Objective (water quality): a numerical concentration limit or narrative statement which has been established to support and protect the designated uses of water at a specified site (CCREM, 1987).

Octanol-water partition coefficient (P_{ow}): the ratio of a chemical's solubility in n-octanol and water at equilibrium. The logarithm of P_{ow} is used as an indication of a chemical's propensity for bioconcentration by aquatic organisms (CCREM, 1987).

Persistent toxic substance: any toxic substance with a half-life in water of greater than eight weeks (GLWQA, 1978).

Point Source: a source of pollution that is distinct and identifiable, such as an outfall pipe from an industrial plant (UGLCCS, 1989).

Primary Track Chemicals: These chemicals are Great Lakes contaminants of known concern, for which abatement and corrective action has been taken, but for which additional measures are required because of their continued presence in the ecosystem at unacceptable levels. They were selected by the IJC. (IJC, 1987b)

Range: the difference between the lowest and highest values in a set of data (CCREM, 1987).

Remedial Action Plan: this is a plan to be developed with citizen involvement to restore and protect water quality at each of the 42 "areas of concern" in the Great Lakes Basin. The RAP will identify impaired uses, sources of contaminants, desired use goals, target clean-up levels, specific remedial options, schedules for implementation, resource commitments by Michigan and Ontario as well as by the federal governments, municipalities and industries, and monitoring requirements to assess the effectiveness of the remedial options implemented (UGLCCS, 1989).

Resuspension: the remixing of sediment particles and pollutants back into the water by storms, currents, organisms and human activities such as dredging (UGLCCS, 1989).

Suspended Sediments/Solids: particulate matter suspended in water (UGLCCS, 1989).

Teratogen: an agent that increases the incidence of congenital malformations (CCREM, 1987).

Toxic Substance: A substance that can cause death, disease, behavioral abnormalities, cancer, genetic mutations, physiological or reproductive malfunctions, or physical deformities in any organisms or its offspring or that can become poisonous after concentration in the food chain or in combination with other substances (NRC and RSC, 1985).

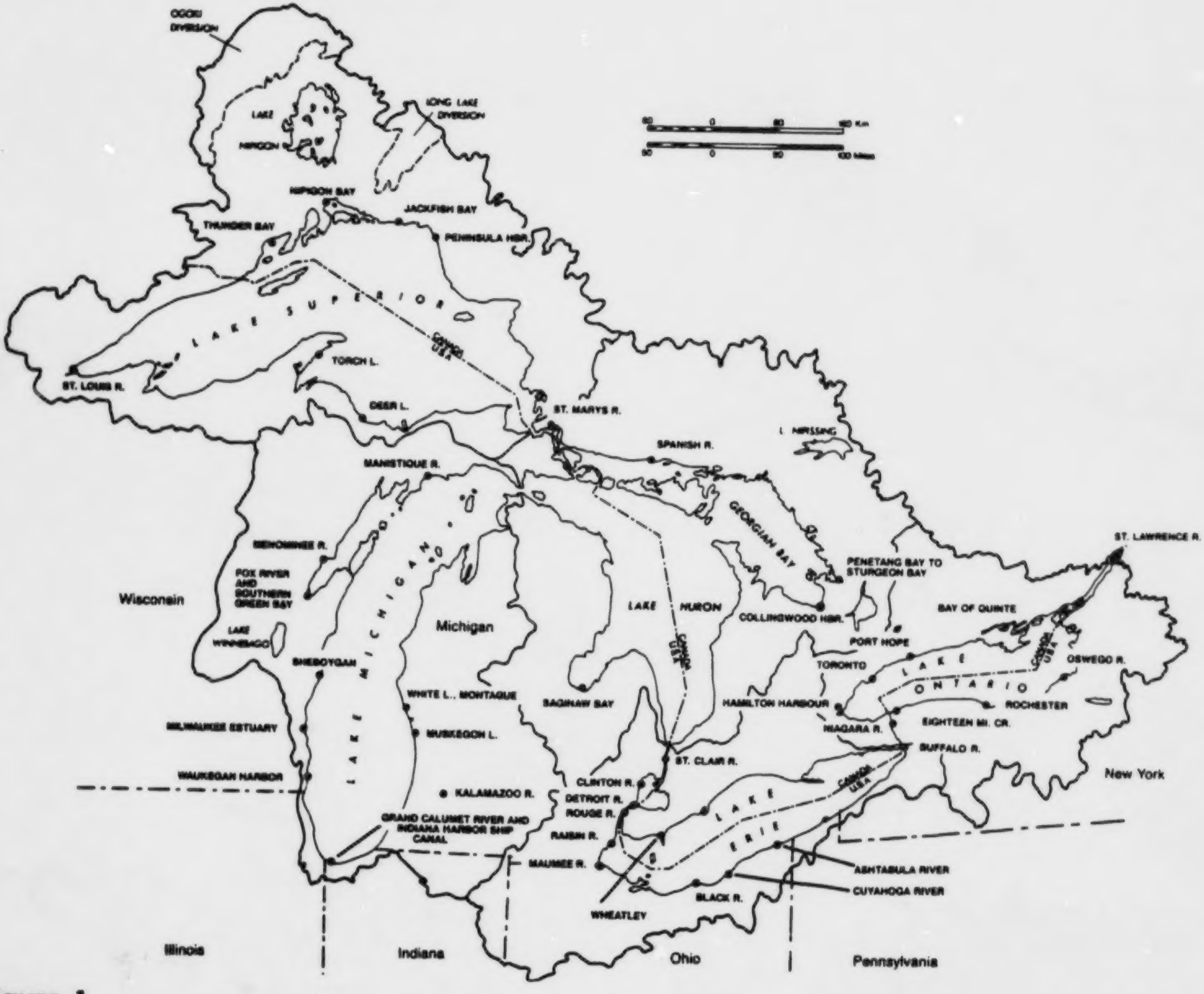
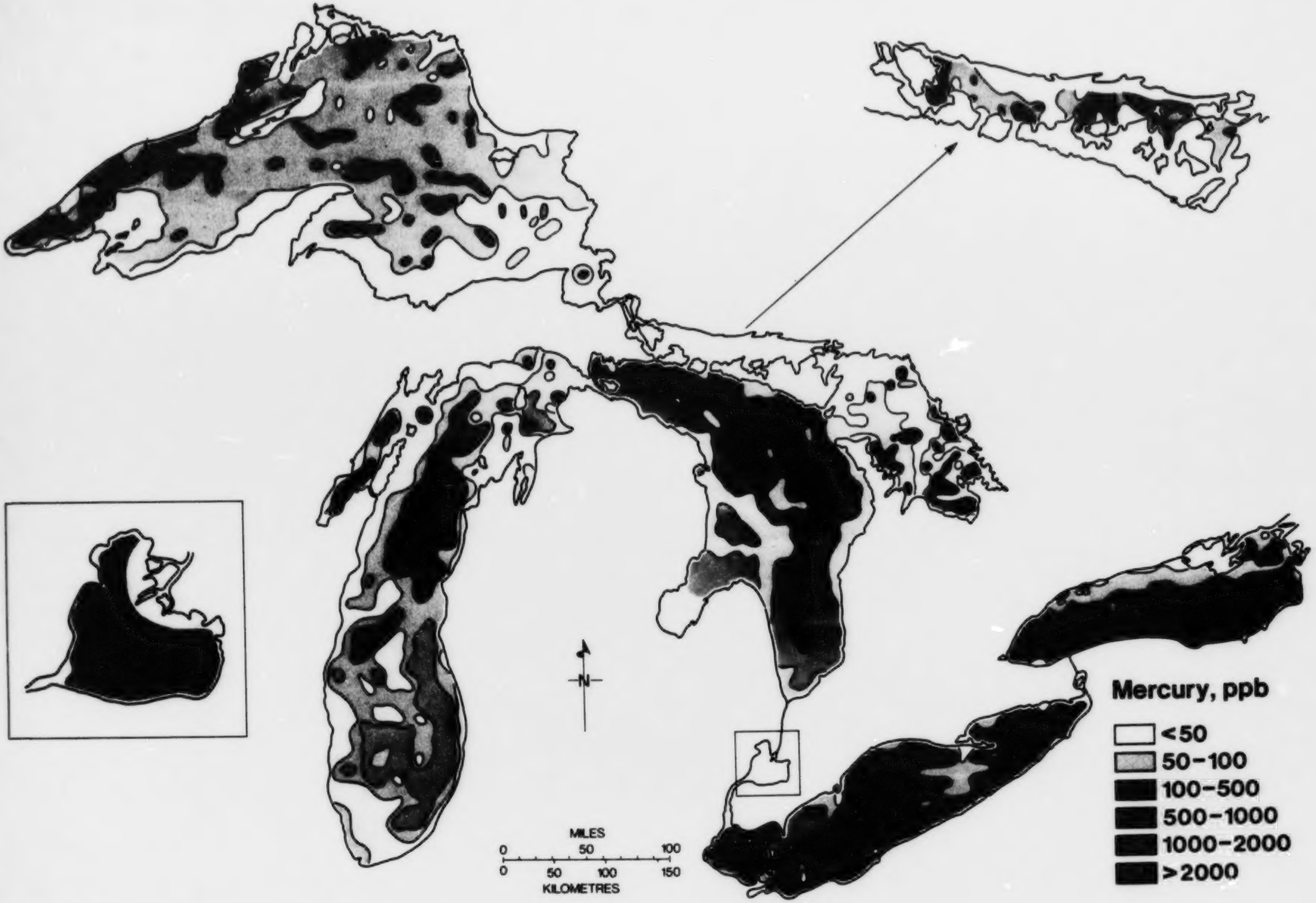

OGOKI DIVERSION
LAKE NIPIGON
LONG LAKE DIVERSION
NIPIGON BAY
JACKFISH BAY
THUNDER BAY
PENINSULA HBR.
LAKE SUPERIOR
CANADA U.S.A.
ST. LOUIS R.
TORCH L.
DEER L.
ST. MARYS R.
SPANISH R.
L. NIPISSING
MANISTIQUE R.
GEORGIAN BAY
MENOMINEE R.
ST. LAWRENCE R.
PENETANG BAY TO STURGEON BAY
FOX RIVER AND SOUTHERN GREEN BAY
Wisconsin
LAKE MICHIGAN
Michigan
LAKE HURON
COLLINGWOOD HBR.
BAY OF QUINTE
LAKE WINNEBAGO
PORT HOPE
SHEBOYGAN
TORONTO
LAKE ONTARIO
OSWEGO R.
WHITE L., MONTAGUE
SAGINAW BAY
HAMILTON HARBOUR
ROCHESTER
MILWAUKEE ESTUARY
MUSKEGON L.
NIAGARA R.
EIGHTEEN MI. CR.
ST. CLAIR R.
BUFFALO R.
WAUKEGAN HARBOR
CLINTON R.
New York
KALAMAZOO R.
DETROIT R.
ROUGE R.
LAKE ERIE
GRAND CALUMET RIVER AND INDIANA HARBOR SHIP CANAL
RAISIN R.
MAUMEE R.
ASHTABULA RIVER
CUYAHOGA RIVER
BLACK R.
WHEATLEY
Illinois
Indiana
Ohio
Pennsylvania

Figure 1

The Great Lakes drainage basin (showing Areas of Concern).


Mercury, ppb
<50
50–100
100–500
500–1000
1000–2000
>2000
N
MILES
0
50
100
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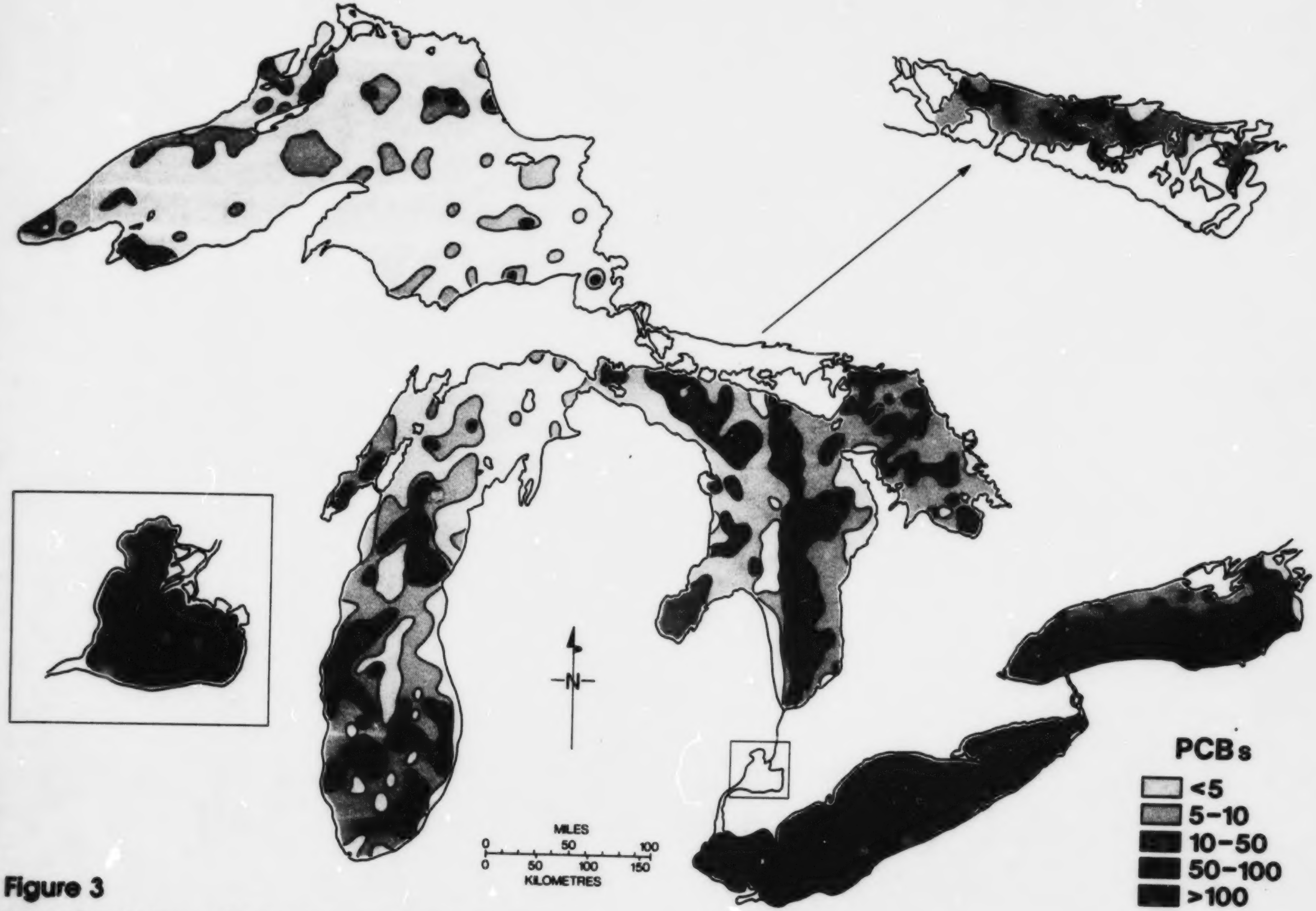
50
100
150
KILOMETRES

Figure 2

Hg in Great Lakes sediments. (Thomas and Mudroch, 1979)


PCBs
<5
5–10
10–50
50–100
>100
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150
KILOMETRES

Figure 3

PCBs In Great Lakes sediments. (Thomas and Frank, 1983)

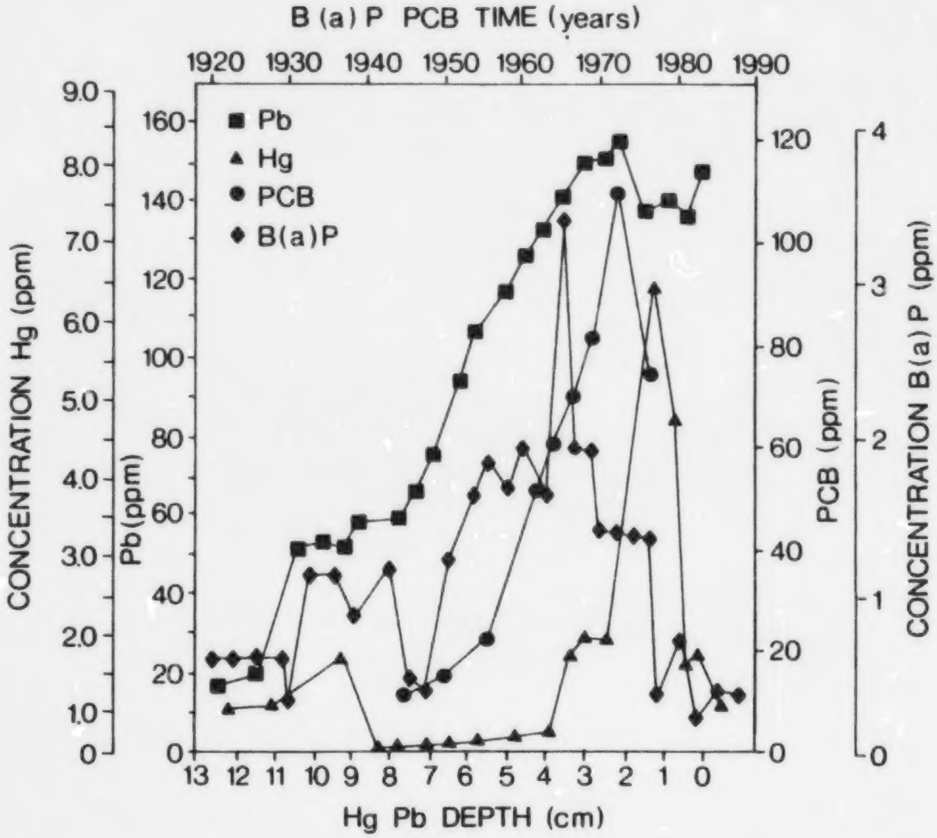


Figure 4

Distribution of Hg, Pb, PCBs in Lake Superior and B(a)P in Lake St. George sediment cores. (After Rossmann, 1986; Charles and Hites, 1987; UGLCCS, 1989)

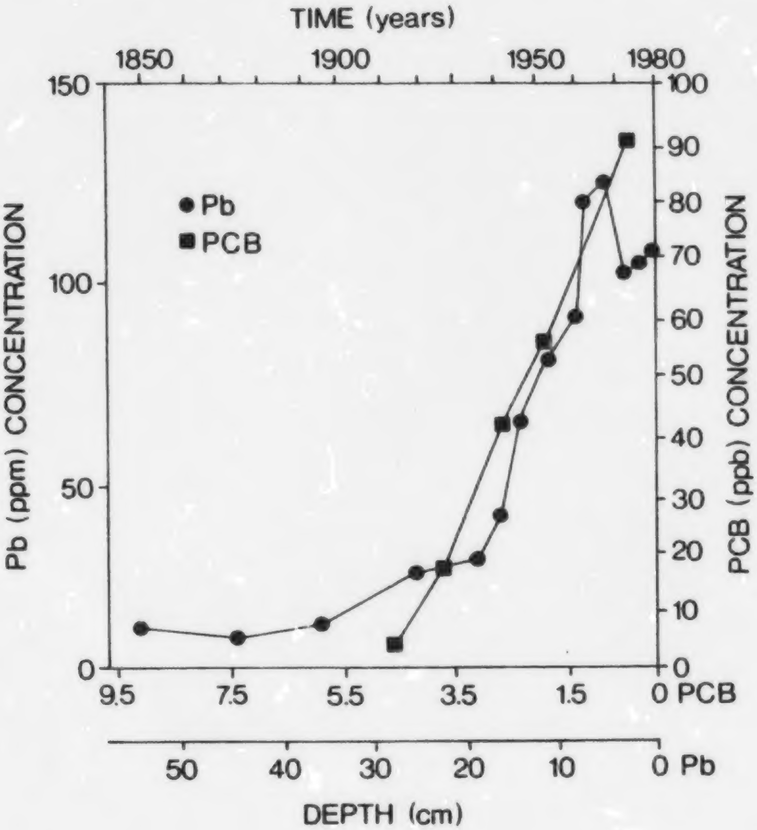


Figure 5

Distribution of Pb and PCBs in Lake Michigan sediment cores. (After Goldberg *et al.*, 1981; Swackhammer and Armstrong, 1986)

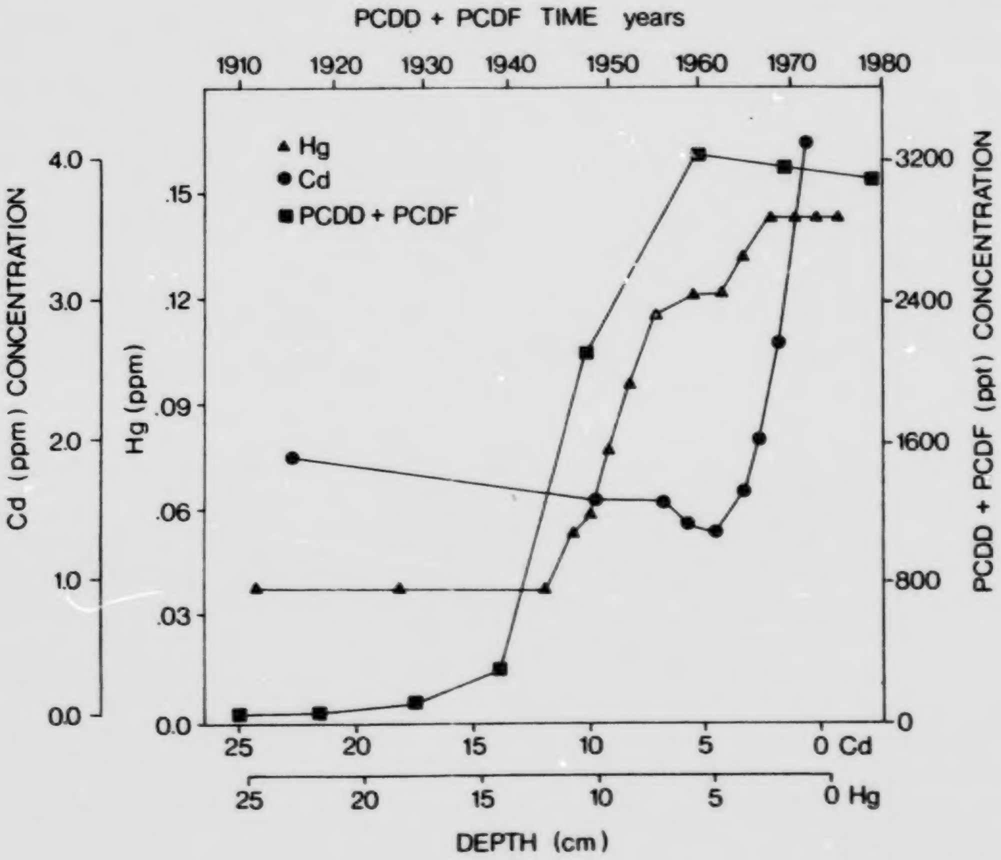


Figure 6

Distribution of Cd, Hg and PCDD + PCDF in Lake Huron sediment cores. (After Robbing, 1980; Czuczwa and Hites, 1984)

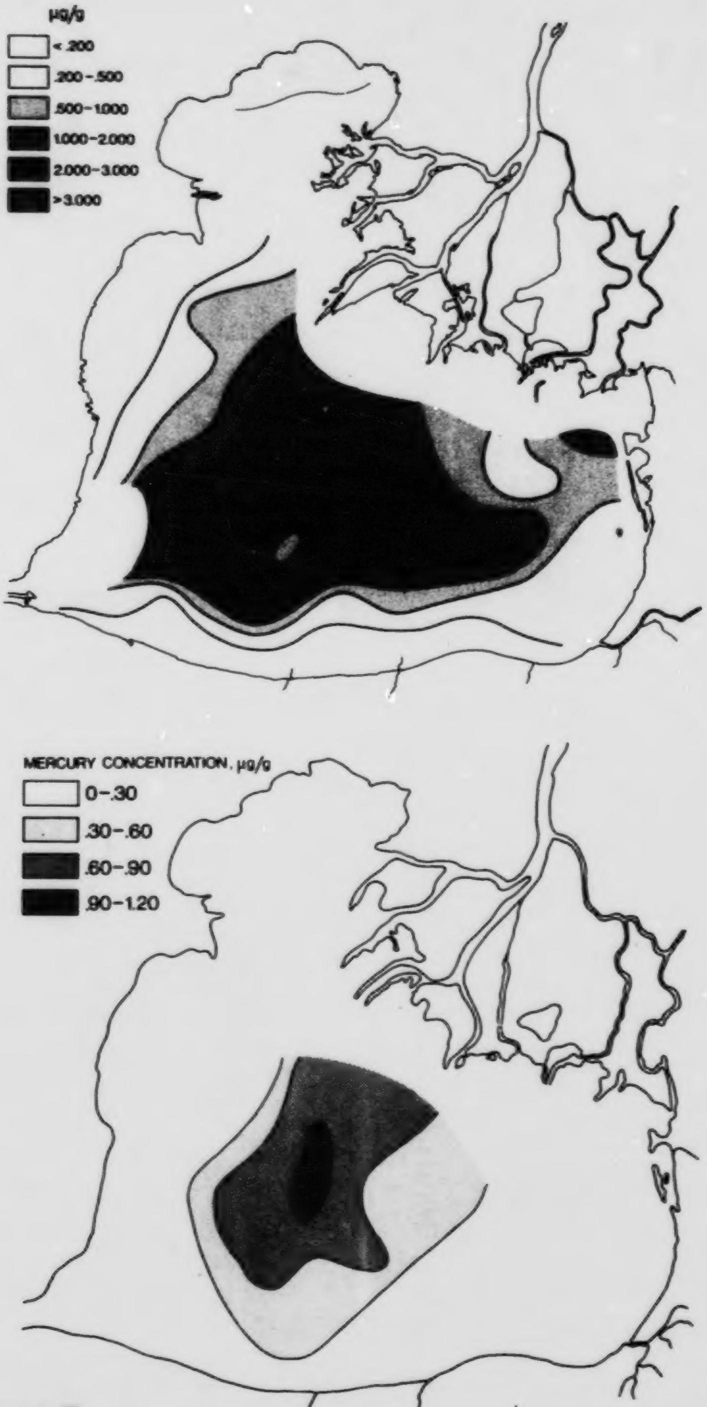

µg/g
< .200
.200 - .500
.500 - 1.000
1.000 - 2.000
2.000 - 3.000
> 3.000
MERCURY CONCENTRATION, µg/g
0 - .30
.30 - .60
.60 - .90
.90 - 1.20

Figure 7

Distribution of Hg in the surface sediments of Lake St. Clair, 1970 (after Thomas *et al.*, 1975) and 1985 (Mudroch and Hill, 1987)

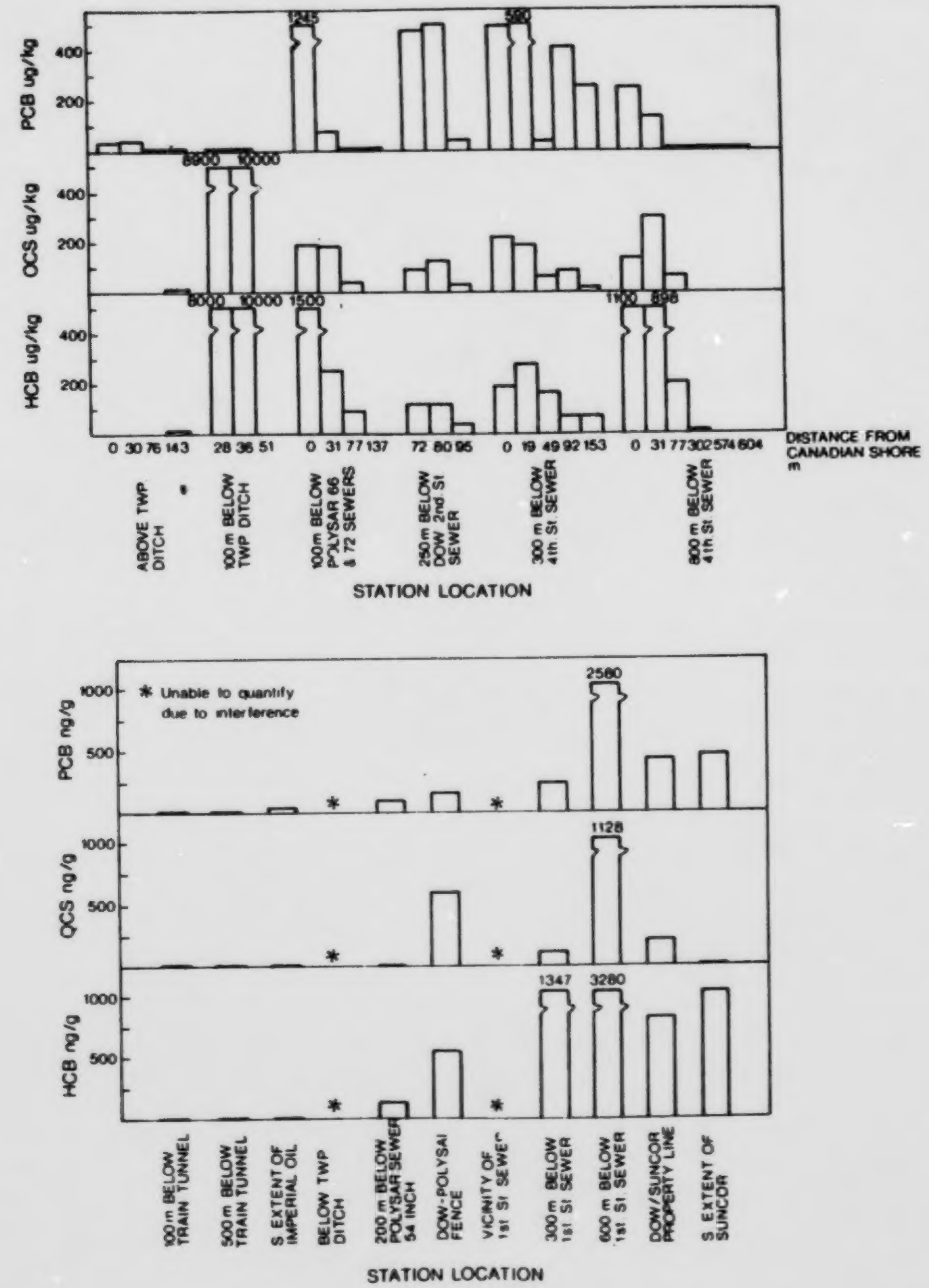
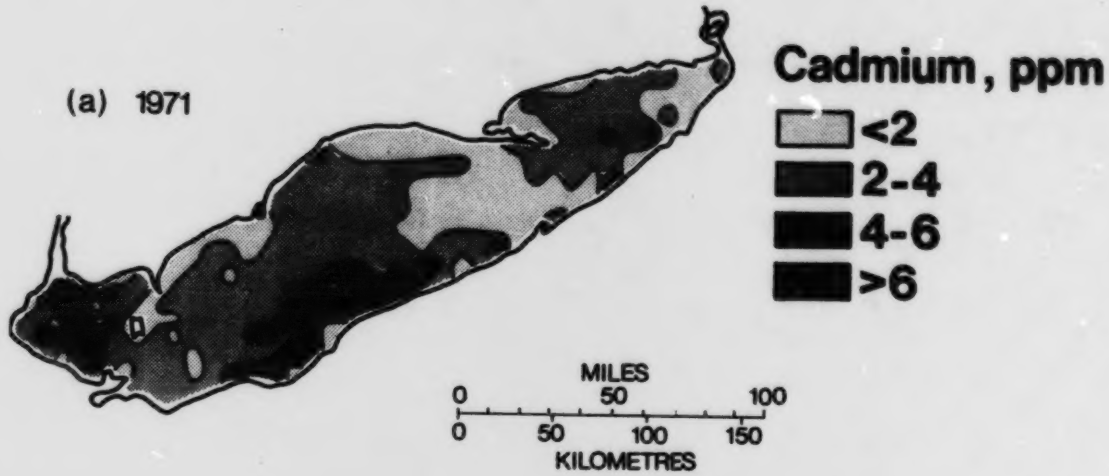


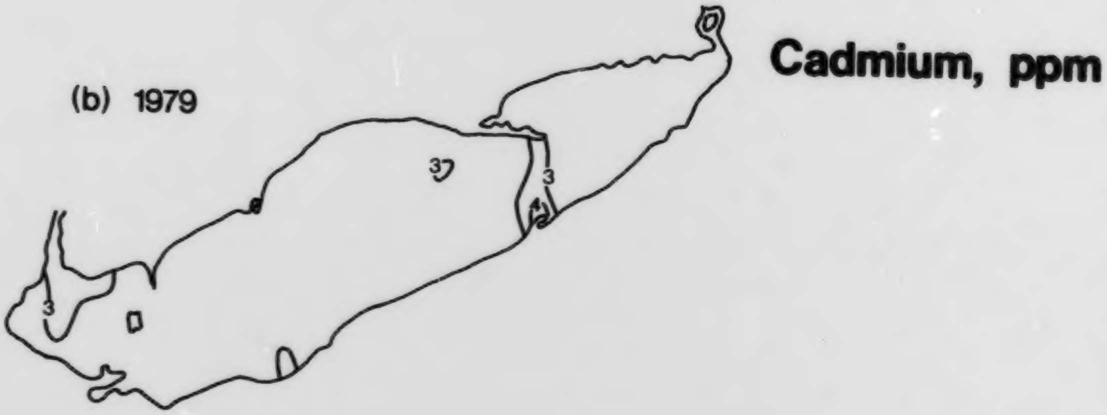
Figure 8

Concentrations of contaminants in sediments of St. Clair River, 1983 and 1985. (DOE and MOE, 1986)



(a) 1971

Cadmium, ppm
<2
2-4
4-6
>6
MILES
0
50
100
0
50
100
150
KILOMETRES



(b) 1979

Cadmium, ppm
3
3
3
4

Figure 9

Cd in surficial bottom sediments of Lake Erie (a) 1971 (after Thomas and Mudroch, 1979) and (b) 1979 (Rathke, 1984).

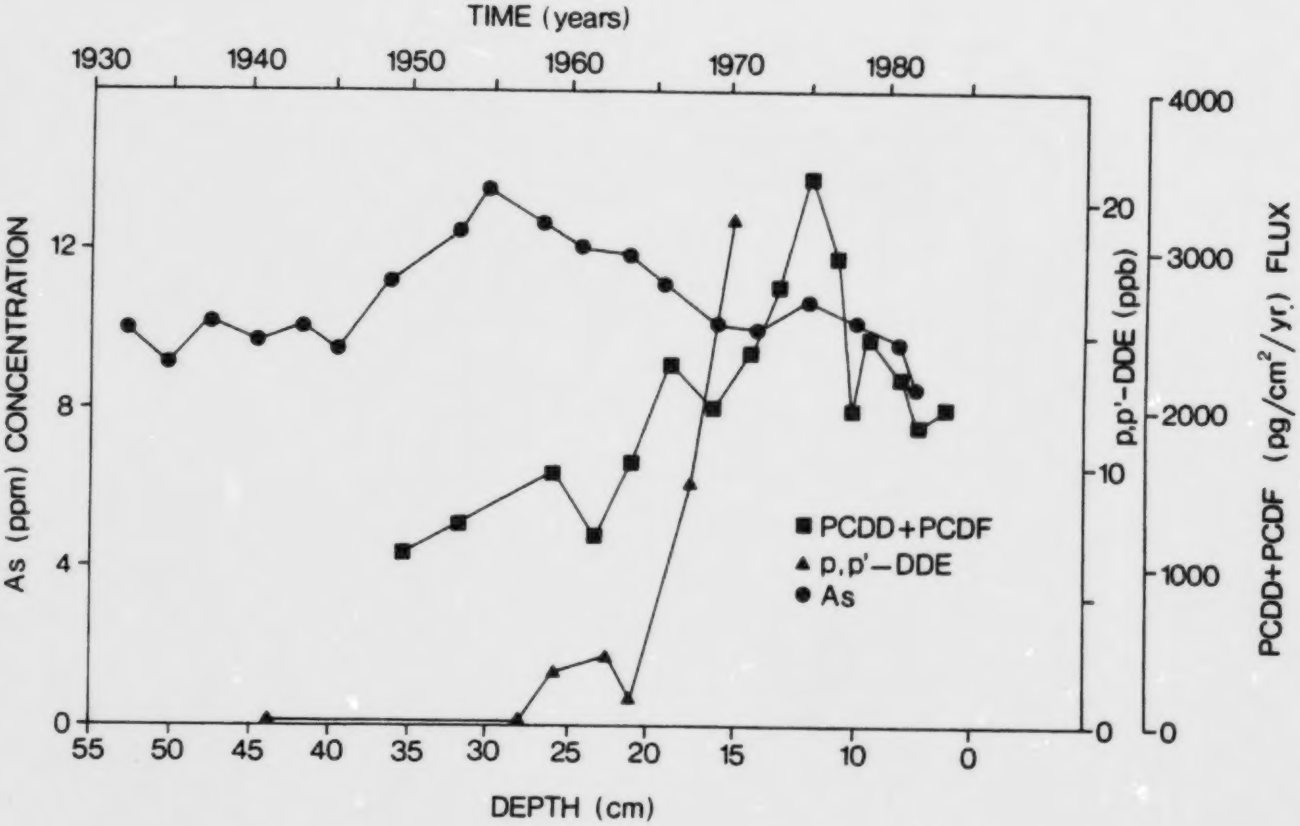


Figure 10

Distribution of As, DDE and PCDD + PCDF sediment cores from Lake Erie. (After Czuczwa and Hites, 1986a; Legault, 1986, Frank *et al.*, 1977)

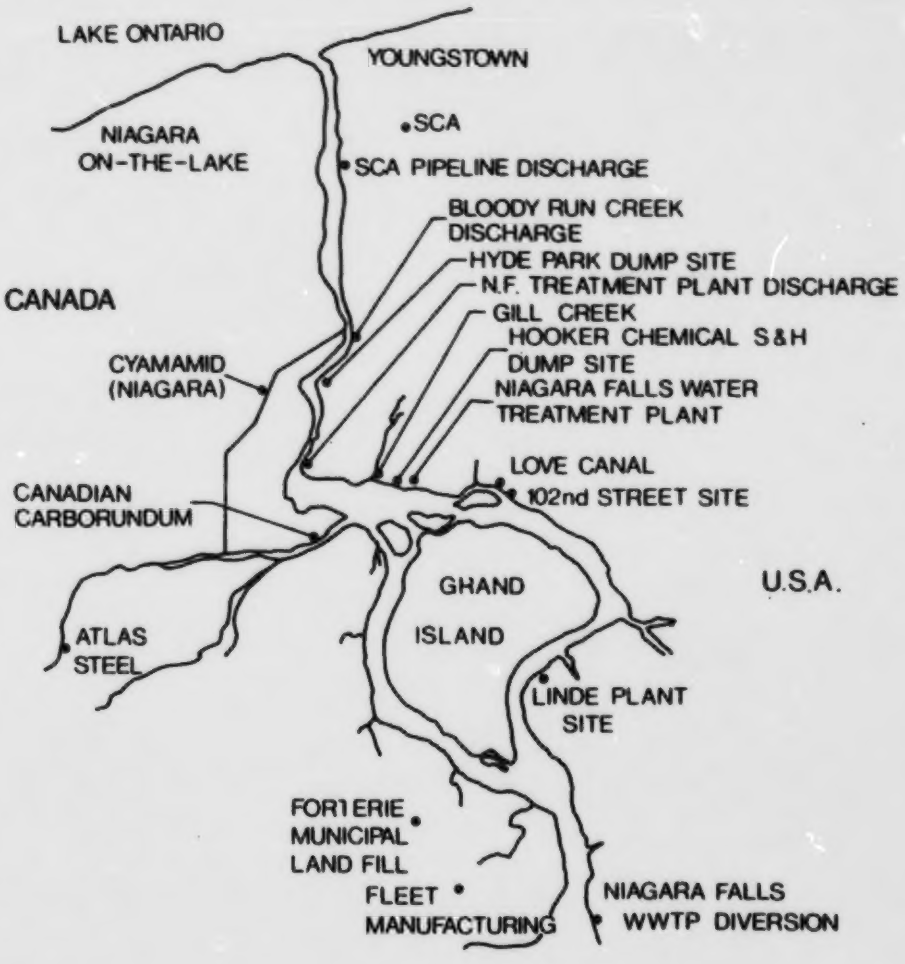

LAKE ONTARIO
YOUNGSTOWN
SCA
NIAGARA ON-THE-LAKE
SCA PIPELINE DISCHARGE
BLOODY RUN CREEK DISCHARGE
HYDE PARK DUMP SITE
N.F. TREATMENT PLANT DISCHARGE
CANADA
GILL CREEK
HOOKER CHEMICAL S&H DUMP SITE
CYAMAMID (NIAGARA)
NIAGARA FALLS WATER TREATMENT PLANT
LOVE CANAL
CANADIAN CARBORUNDUM
102nd STREET SITE
GRAND ISLAND
U.S.A.
ATLAS STEEL
LINDE PLANT SITE
FORT ERIE MUNICIPAL LAND FILL
FLEET MANUFACTURING
NIAGARA FALLS WWTP DIVERSION

Figure 11

Major effluent outfalls and waste dumps adjacent to the Niagara River. (Allan *et al.*, 1983)

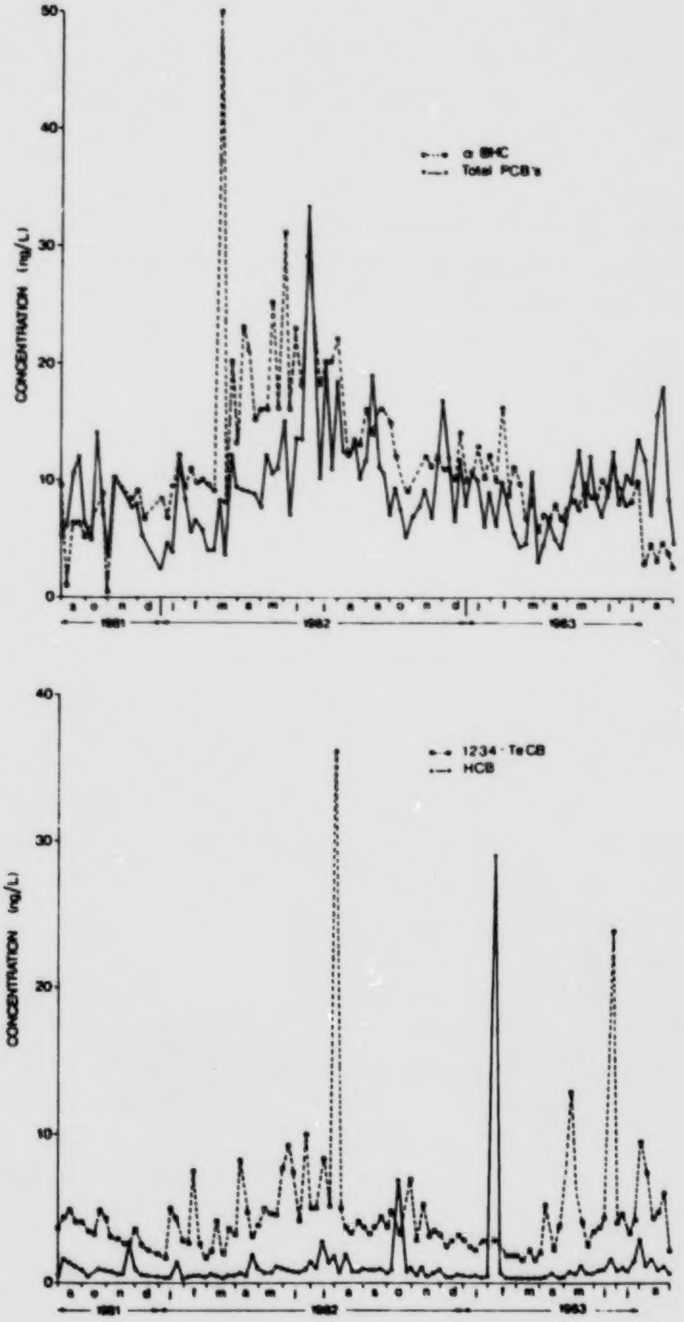
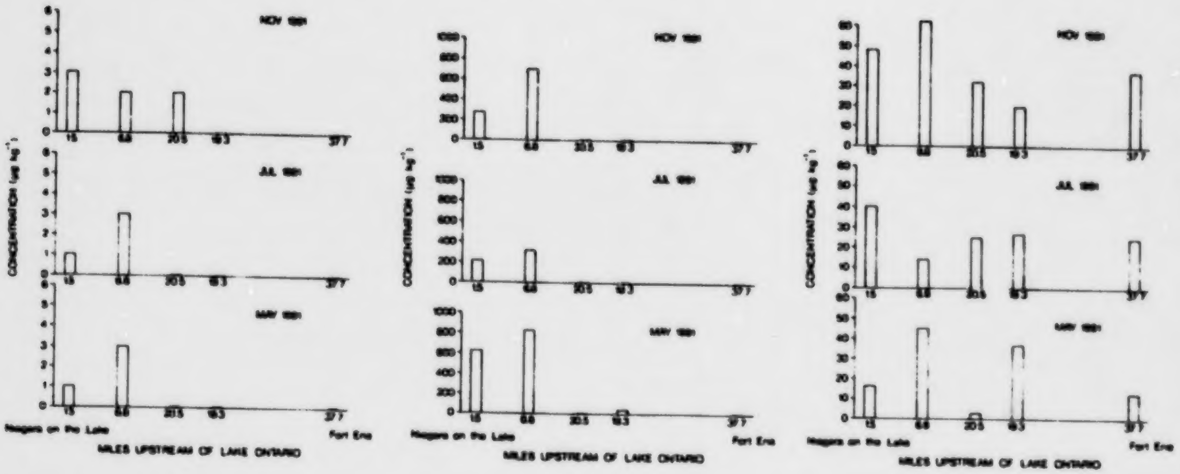
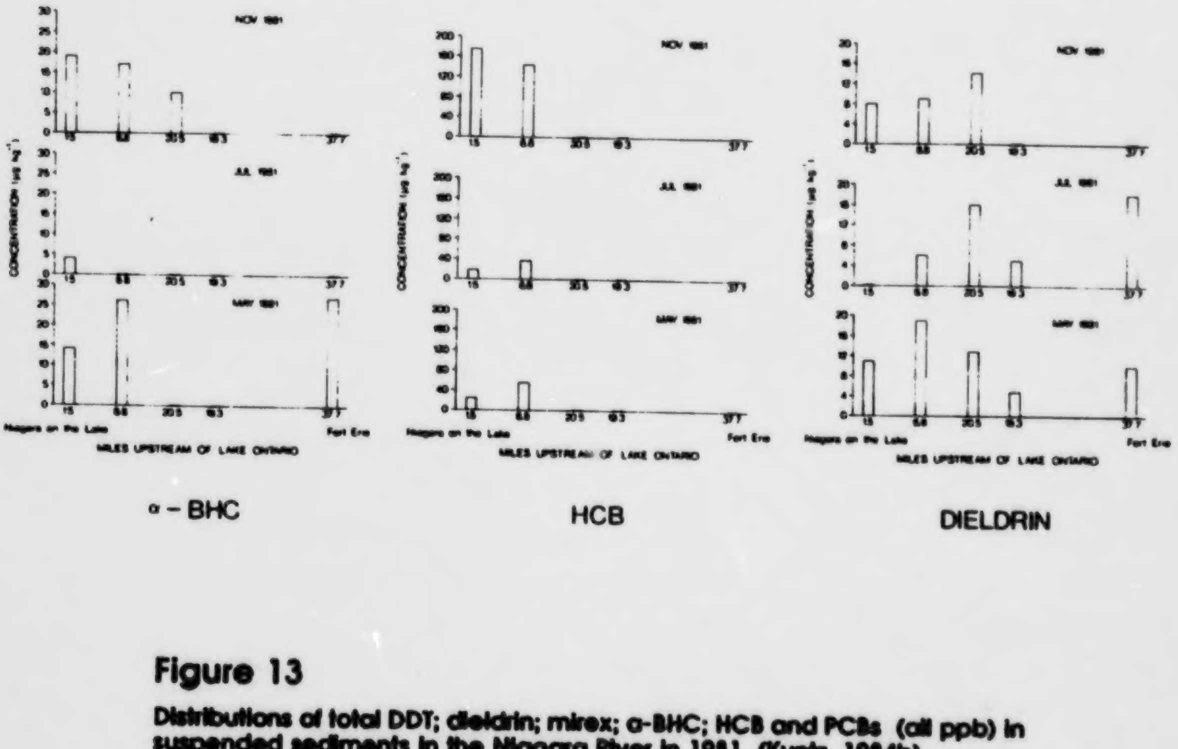


Figure 12

Concentrations of organic chemicals in weekly water samples from NOTL between 1981 and 1983. (Oliver and Nicol, 1984)



MIREX **Total PCBs** **Total DDT**



α – BHC **HCB** **DIELDRIN**

Figure 13

Distributions of total DDT; dieldrin; mirex; α-BHC; HCB and PCBs (all ppb) in suspended sediments in the Niagara River in 1981. (Kuntz, 1984b)

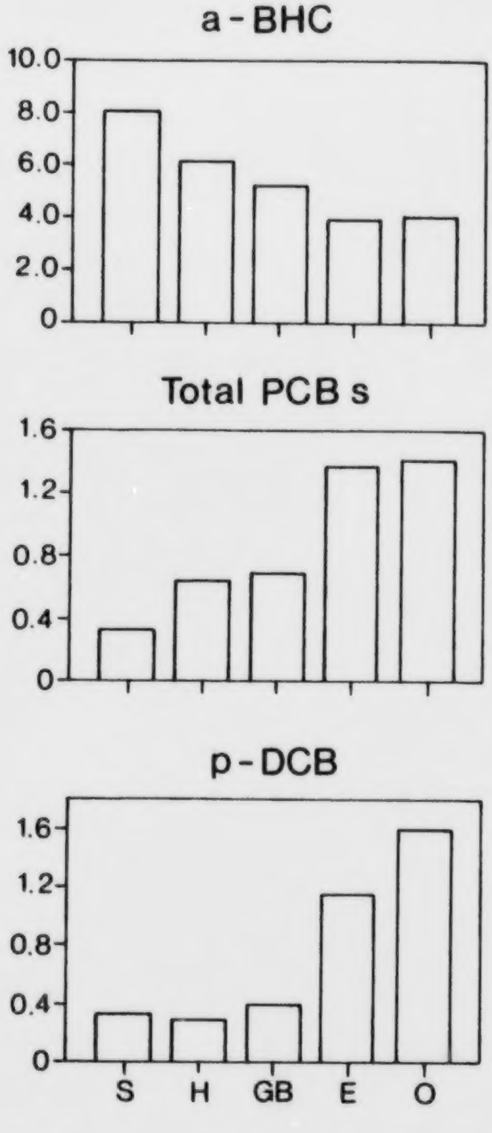


Figure 14

Inter lake comparison of mean concentrations of a-BHC, total PCBs and p-DCB (ng.L^{-1}). (All compounds were detected at 100% of stations sampled in each lake. Superior; Huron; Erie; Ontario; Georgian Bay) (Stevens and Neilson, in press)

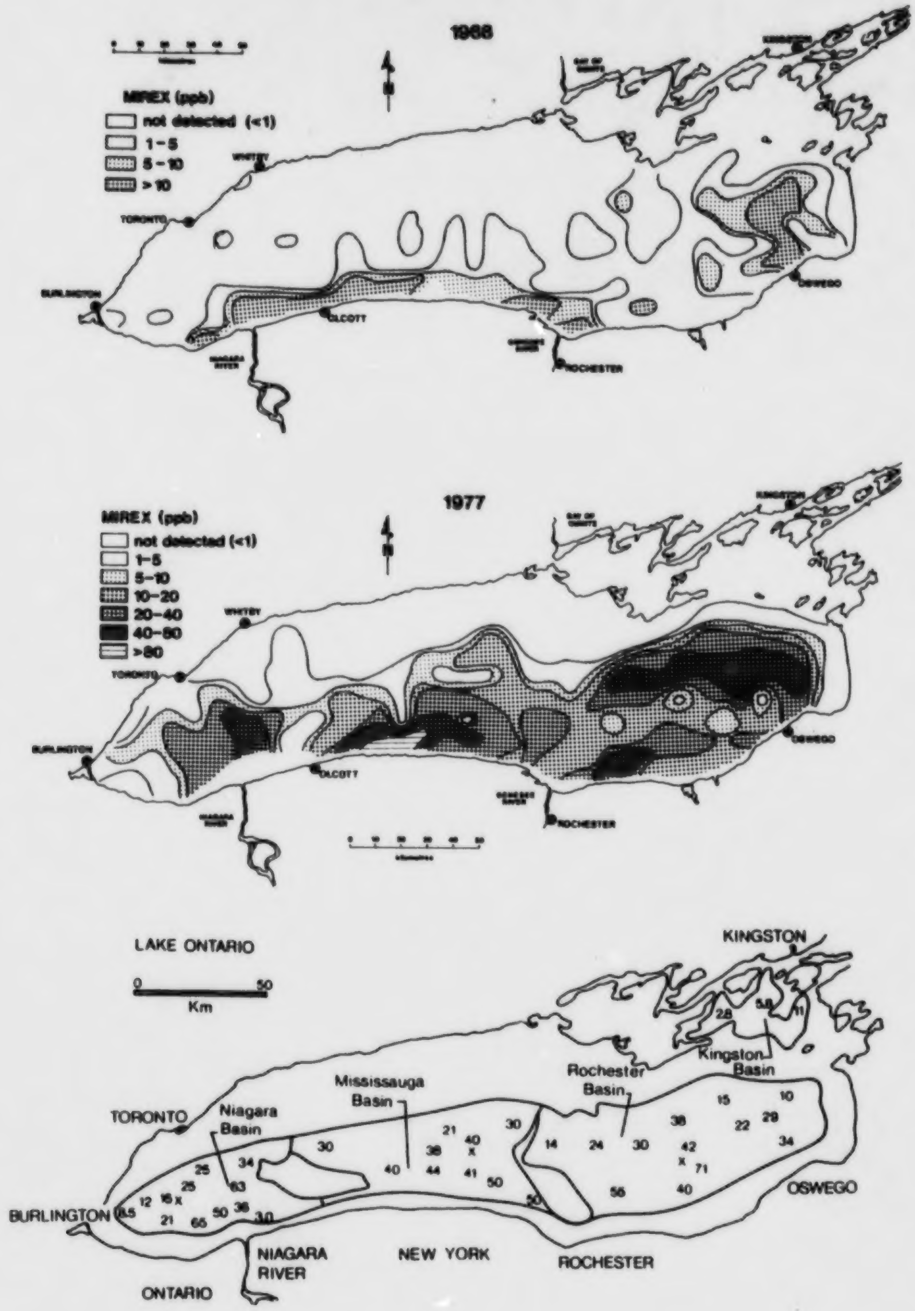

1968
MIREX (ppb)
not detected (<1)
1-5
5-10
>10
KINGSTON
WHITBY
TORONTO
BURLINGTON
OLCOTT
NIAGARA RIVER
GENESEE RIVER
ROCHESTER
OSWEGO
1977
MIREX (ppb)
not detected (<1)
1-5
5-10
10-20
20-40
40-80
>80
KINGSTON
WHITBY
TORONTO
BURLINGTON
OLCOTT
NIAGARA RIVER
GENESEE RIVER
ROCHESTER
OSWEGO
LAKE ONTARIO
0
50
Km
KINGSTON
28
58
11
Kingston Basin
Rochester Basin
Mississauga Basin
TORONTO
Niagara Basin
15
10
38
22
29
34
30
21
40
x
30
14
24
30
42
x
71
25
34
38
40
44
41
50
56
40
OSWEGO
25
63
12
16
x
50
BURLINGTON
85
21
65
50
36
30
NIAGARA RIVER
NEW YORK
ROCHESTER
ONTARIO

Figure 15

Concentration of mirex (ppb) in 3 cm surficial sediments of Lake Ontario, (a) 1968 (Holdrinet *et al.*, 1978); (b) 1977 (Thomas *et al.*, 1988); and (c) 1981 (Oliver *et al.*, 1987).

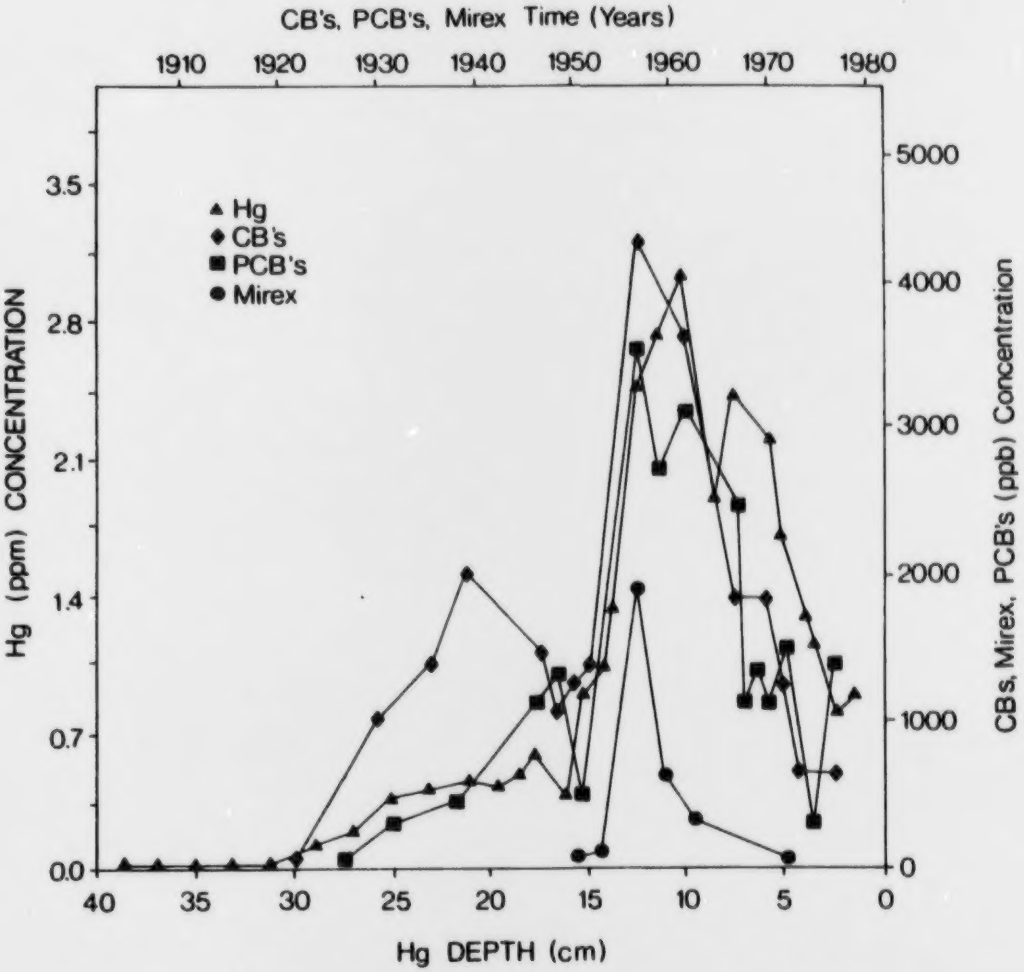


Figure 16

Distributions of mirex, CBs and PCBs in sediment cores from the Niagara River Delta (after Durham and Oliver, 1983) and distribution of Hg in sediment cores from eastern Lake Ontario (after Eadie *et al.*, 1983).

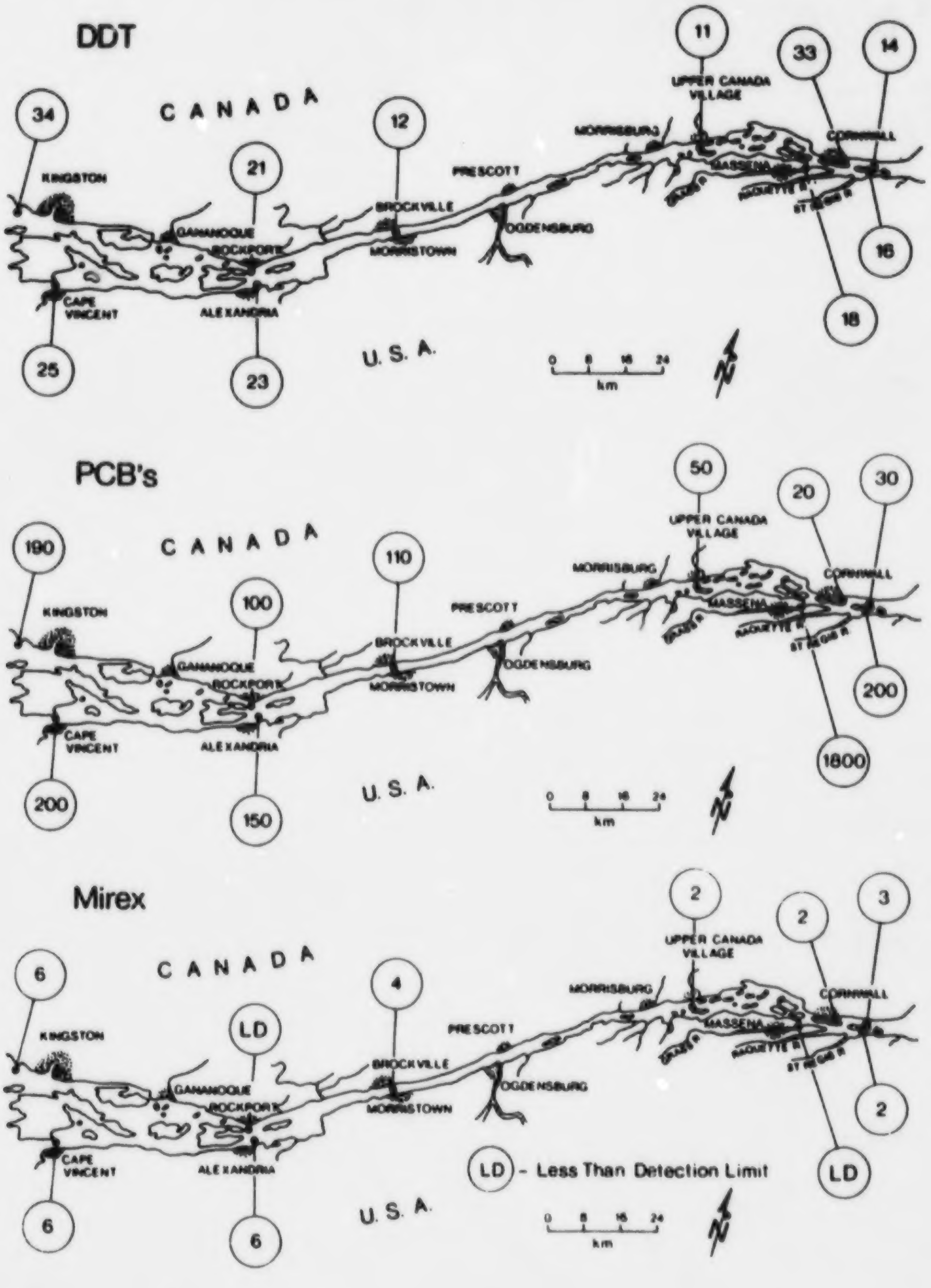

DDT
CANADA
U. S. A.
KINGSTON
GANANOQUE
ROCKPORT
CAPE VINCENT
ALEXANDRIA
BROCKVILLE
MORRISTOWN
PRESCOTT
OGDENSBURG
MORRISBURG
UPPER CANADA VILLAGE
MASSENA
CORNWALL
RAQUETTE R.
ST REGIS R.
GRASS R.
34
25
21
23
12
11
33
14
16
18
0 8 16 24
km
N
PCB's
190
200
100
150
110
50
20
30
200
1800
Mirex
6
6
LD
6
4
2
2
3
2
LD
LD - Less Than Detection Limit

Figure 17

Total DDT and metabolites; PCBs and mirex in suspended solids in the St. Lawrence River in 1981 measured in ppb. (Merriman, 1987)

TABLE 1. PHYSICAL FEATURES OF THE GREAT LAKES

	Superior	**Michigan**	**Huron**	**Erie**	**Ontario**	**Totals**
Elevation (m)	183	176	176	173	74	
Length (km)	563	494	332	388	311	
Breadth (km)	257	190	245	92	85	
Average Depth (m)	147	85	59	19	86	
Maximum Depth (m)	405	281	229	64	244	
Volume (km^3)	12,100	4,920	3,540	484	1,640	22,684
Area:						
Water (km^2)	82,100	57,800	59,600	25,700	18,960	244,160
Land Drainage Area (km)	127,700	118,000	134,100	78,000	64,030	521,830
Total (km^2)	209,800	175,800	193,700	103,700	82,990	765,900
Shoreline Length (km)	4,385	2,633	6,157	1,402	1,146	17,017
Retention Time (years)	191	99	22	2.6	6	
Population:						
U.S. (1980)	558,100	13,970,900	1,321,000	11,347,500	2,090,300	29,287,800
Canada (1981)	180,440		1,051,119	1,621,106	4,551,875	7,404,540
Totals	738,540	13,970,900	2,372,119	12,968,606	6,662,175	36,692,340
Outlet	St. Mary's River	Straits of Mackinac	St. Clair River	Niagara River Welland Canal	St. Lawrence River	

Source: after Botts, L. and B. Krushelnicki, 1987.

TABLE 2. WATER QUALITY AGREEMENT OBJECTIVES FOR THE MAIN CHEMICALS DISCUSSED

	1978 GREAT LAKES WATE QUALITY AGREEMENT SPECIFIC OBJECTIVE[1] ppb (µg/L)	CCREM WATER QUALITY GUIDELINES FOR AQUATIC LIFE[2] ppb(µg/L)
Lead	10-25 (2-5)[3,4]	1.0-7.0[5]
Mercury	0.2[6]	0.1
Cadmium	0.2	0.2-1.8[5]
Arsenic	50.0	50.0
DDT[7]	0.003	0.001
Aldrin/Dieldrin	0.001	-
Dieldrin	-	0.004
BHC	(0.02)	0.01
Lindane	0.01	-
Toxaphene	0.008	0.008
PCBs[8]	(0.001)	0.001
HCB	-	0.0065
HCBD	-	0.1
2,3,7,8-TCDD	DL[9] (0.00001)	-
B(a)P	(0.01)	-
Mirex	DL (0.005)	-

[1] IJC 1987c. These specific objectives are from the 1978 Great Lakes Water Quality Agreement or those subsequently approved by the IJC. Unfiltered water sample.

[2] Canadian Council of Resource and Environmental Ministers 1987. Unfiltered water sample.

[3] Values in brackets are recommendations only by Ecosystems Objectives Committee of IJC.

[4] Concentration depends on lake (the lower lakes have higher objectives than the upper lakes).

[5] Concentration depends on water hardness (the harder the water, the higher the guideline).

[6] Filtered water sample.

[7] Total DDT.

[8] Total PCBs.

[9] Detection Limit. "For other organic contaminants, for which Specific Objectives have not been defined, but which can be demonstrated to be persistent and are likely to be toxic, the concentrations of such compounds in water or aquatic organisms should be substantially absent, i.e. less than detection levels as determined by the best scientific methodology available" (IJC 1978). The first set of objectives listed are the 1978 Great Lakes Water Quality Agreement Specific Objectives. These were amended by the 1987 Protocol. Although the Protocol stated that the discharge of toxic substances in toxic amounts be prohibited and the discharge of any or all persistent toxic substances be virtually eliminated (IJC 1988), the Specific Objectives listed in the revised 1978 Agreement were adopted in 1987 as interim objectives for persistent toxic substances. The second set of guidelines are those proposed by the Canadian Council for Resource and Environment Ministers. In 1984, CCREM approved the recommendation by the Task Force on Water Quality Guidelines that Canadian water quality guidelines be harmonized (CCREM 1987). The guidelines are presented here as a comparison to the IJC objectives. The introduction to the Task Force report states that the guidelines should not be regarded as blanket values for national water quality and that variations in environmental conditions across Canada will affect water quality in different ways such that many of the guidelines will need to be modified according to local conditions (CCREM, 1987).

TABLE 3. UNITS OF MEASUREMENT

	Dry Weight	**Wet Weight**
ppm parts per million	mg/kg milligram per kilogram	mg/L milligram per litre
ppb parts per billion	µg/kg microgram per kilogram	µg/L microgram per litre
ppt parts per trillion	ng/kg nanogram per kilogram	ng/L nanogram per litre
ppq parts per quadrillion	pg/kg picogram per kilogram	pg/L picogram per litre

TABLE 4. CONCENTRATIONS OF CONTAMINANTS IN LAKE SUPERIOR WATER (ppt)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	dis.	1983	22	ND	100	14	31	6	27	41	(1) (5)
Pb	dis.	<1986				75					(11)
Pb	part.	1977	7	50	4,700	770	1,700	100			(2)
Pb	part.	1983	22	11	48	25	10	23	2	0	(1) (5)
Pb	part.	<1986				25					(11)
Pb	whole	1975	5			400	200				(4)
Pb	whole	1977	7	<300	3,200	1,500	1,300	1,500			(2)
Pb	whole	<1981		1000	1,500						
Pb	whole	1983	22	ND	130	39	34	29	27		(1) (5)
Hg	dis.	1983	22	ND	56	0.91	18	0	6.9	95	(1) (5)
Hg	dis.	<1986				7					(11)
Hg	part.	1983	22	ND	100	7.6	34	1			(1)
Hg	part.	<1986				3					(11)
Hg	whole	1970-71	226	ND	470	180	130		50		(3)
Hg	whole	<1981		50	100						
Hg	whole	1983	22	ND	120	9.8	34	2	6.9	90	(1) (5)
Cd	dis.	1983	22	ND	12	6.6	3	6	2	64	(1) (5)
Cd	dis.	<1986				20					(11)
Cd	part.	1977	7	2	40	10	10	4			(2)
Cd	part.	1983	22	ND	38	21	10	21	3.9	23	(1) (5)
Cd	part.	<1986				20					(11)
Cd	whole	1977	7	<20	250	120	100	130			(2)
Cd	whole	<1981				<200					(12)
Cd	whole	1983	22	70	44	27	10	27	2		(1)
As	dis.	1983	22	400	900	550	130	520	29	0	(1) (5)
As	part.	1983	22	ND	50	11	25	10	50	91	(1) (5)
As	whole	1969	47	ND	1,000	230			100		(13)
As	whole	1975	5			800	100				(4)
As	whole	1983	22	430	900	560	130	520	29		(1)
As	whole	<1986				600					(11)
tDDT	dis.	<1986				0.1					(11)
tDDT	part.	<1986				0.1					(11)
p,p'-DDT	whole	1983	11	0.01	0.513	0.227	0.189	0.39			(6)
o,p'-DDT	whole	1983	3	0.016	0.195	0.113	0.09				(6)
p,p'-DDT	whole	1986	19		ND				0.007	100	(7)
o,p'-DDT	whole	1986	19		ND				0.007	100	(7)
p,p'-DDE	whole	1983	15	0.007	0.041	0.02	0.009				(6)
p,p'-DDE	whole	1983	17	0.005	0.024	0.012	0.006				(8)
p,p'-DDE	whole	1986	19		ND				0.007	100	(7)
dieldrin	dis.	<1986				0.1					(11)
dieldrin	part.	<1986				0.1					(11)
dieldrin	whole	<1981				<5					(12)
dieldrin	whole	1983	15	0.08	0.412	0.205	0.092	0.21			(6)
dieldrin	whole	1986	19	0.231	0.425	0.3			0.007	0	(7)
a-BHC	dis.	<1986				2					(11)
a-BHC	part.	<1986				0.2					(11)
a-BHC	whole	1983	16	2.894	15.891	7.716	3.02	7.78		0	(6)
a-BHC	whole	1986	19	5.712	10.991	8.069			0.007	0	(7)
lindane	dis.	<1986				0.6					(11)
lindane	part.	<1986				0.1					(11)
lindane	whole	1983	16	0.278	2.255	0.766	0.461	0.684		0	(6)
lindane	whole	1986	19	0.802	1.434	1.092			0.007	0	(7)
mirex	whole	1983	1			0.004					(6)
mirex	whole	1986	19						0.007	100	(7)
toxaphene	dis.	<1986				0.4					(11)
toxaphene	part.	<1986				0.2					(11)
toxaphene	whole	1981				0.5					(9)
B(a)P	dis.	<1986				0.07					(11)
B(a)P	part.	<1986				0.03					(11)
HCB	dis.	<1986				0.01					(11)
HCB	part.	<1986				0.01					(11)
HCB	whole	1983	16	0.011	0.051	0.028	0.01	0.025			(6)

TABLE 4. CONTINUED

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
HCB	whole	1983	17	0.01	0.049	0.023	0.009				(8)
HCB	whole	1986	19	0.018	0.04	0.026			0.007	0	(7)
PCBs	dis.	1978				1.3	1.3				(15)
PCBs	dis.	1986				0.55	0.37				(14)
PCBs	dis.	<1986				0.4					(11)
PCBs	part.	<1986				0.2					(11)
PCBs	whole	1978-80	126	0.3	8.4	1.8	0.2				(10)
PCBs	whole	<1981		1	4	<100					(12)
PCBs	whole	1983	16	1.166	5.113	2.363	1.088	1.94			(6)
PCBs	whole	1983	17	0.32	1.07	0.63	0.24				(8)
PCBs	whole	1986	19	0.193	0.578	0.337			0.17	0	(7)

ND : not detected
Sample : whole = whole water; dis. = aqueous phase; part. = suspended particulate phase.
# : number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Rossmann 1986. Particulate conc.: ppt=ng/L. Filter: 0.5 um pore size. Particulate conc. + dissolved conc. = whole water concentration.
2. Eisenreich 1982. Particulate conc.: ppt=ng/L. Filter: 0.4 um pore size.
3. Chau and Saitoh 1973
4. Poldoski *et al.* 1978
5. Rossmann and Barres 1988. The number presented for "% below detection" actually represents the percent of analyses below the limit or criterion of detection. Particulate concentrations are ng/l.
6. Chan 1984
7. Stevens and Nielson in press
8. Baker et. al. 1985. All samples were from the same site in western Lake Superior.
9. Sullivan and Armstrong 1985
10. Eisenreich 1987
11. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models. Part. conc.: ppt=ng/L. Particulate conc. + dissolved conc. = whole water conc.
12. Sonzogni and Simmons 1981. Typical concentration ranges. These values are designed only to illustrate the types of values and the relative range of concentrations reported.
13. Traversy *et al.* 1975
14. Baker and Eisenreich 1989
15. Capel and Eisenreich 1985

TABLE 5. CONCENTRATIONS OF CONTAMINANTS IN BOTTOM SEDIMENTS FROM LAKE SUPERIOR (ppb)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	3 cm	1973	404			44,000	27,000				(11)
Pb	1 cm	1973	5	74,900	143,900	120,000	25,607	133,400			(1)
Pb		<1981		<50,000	150,000	50,000					(8)
Pb		<1984		74,900	138,210						(10)
Pb		<1986				100,000					(9)
Hg	3 cm	1973	404			83	56				(11)
Hg	1 cm	1973	5	94	356	190	91	160			(1)
Hg		<1981		30	300	100					(8)
Hg		<1984		94	160						(10)
Hg		<1986				100					(9)
Cd	3 cm	1973	404			1,200	800				(11)
Cd	1 cm	1973	5	1,400	2,500	2,200	445	2,500			(1)
Cd		<1981		500	2,500	1,000					(8)
Cd		<1984		1,400	2,500						(10)
Cd		<1986				600					(9)
As	3 cm	1973	404			1,700	2,500				(11)
As	3 cm	1973	15	500	8,000	2,033	2,429	800			(2)
tDDT		<1986				8					(9)
p,p'-DDE	3 cm	1973	405	ND	23	0.71	1.65		0.25	66	(5)
DDE	3 cm	1983	6	2.2	7.6	4.6	1.9				(3)
dieldrin	3 cm	1973	405	ND	1.9	<0.25			0.25	95	(5)
dieldrin		<1986				20					(9)
a-BHC		<1986				0.8					(9)
lindane		<1986				0.1					(9)
B(a)P			1			28					(7)
B(a)P		<1986				30					(9)
B(a)P		1986	3	32	40	45	14				(12)
HCB	3 cm	1980	13	0.02	0.7	0.2					(4)
HCB	3 cm	1983	6	0.7	1.8	2.4	0.4				(3)
HCB		<1986				0.2					(9)
HCBD	3 cm	1983	6	0.1	0.1	0.1					(3)
PCBs	3 cm	1973	405	ND	57	3.3	5.7		2.5	78	(5)
PCBs	0.5 cm	1977–78	18	5	390	130	110				(6)
PCBs		<1981				200					(8)
PCBs	3 cm	1983	6	14	53	27	12				(3)
PCBs		<1986				30					(9)
PCBs		1986	3	5.32	11.73	8.62	2.62				(12)

ND : not detected
Sample : depth of surficial sediment sample
: number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Kemp *et al.* 1978
2. Traversy *et al.* 1975
3. Bourbonnière *et al.* 1986

4. Oliver and Nicol 1982. Depositional and non-depositional zones.
5. Frank *et al.* 1980a. Depositional and non-depositional zones.
6. Eisenreich *et al.* 1980
7. Eadie 1984
8. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrate the types of values and the relative range of concentrations reported.
9. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models.
10. Mudroch *et al.* 1988. These numbers are a summary of concentration ranges taken from reports published between 1974 and 1984. Concentrations are from surface samples of depositional zones.
11. IJC 1977c
12. Baker and Eisenreich 1989

TABLE 6. CONCENTRATIONS OF CONTAMINANTS IN LAKE MICHIGAN WATER (ppt)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	dis.	1981	11	23	270	150	80	14	33	9	(1), (5)
Pb	dis.	<1986				150					(8)
Pb	part.	<1986				50					(8)
Pb	whole	<1981				7000					(3)
Pb	whole	1981	11	130	480	260	110	250	33	0	(1), (5)
Hg	dis.	1981	11	ND	120	44	33	48	26	27	(1), (5)
Hg	dis.	<1986				37					(8)
Hg	part.	<1986				8					(8)
Hg	whole	<1981				<1000					(3)
Hg	whole	1981	11	ND	110	52	31	45	26	18	(1), (5)
Cd	dis.	1981	11	27	190	56	44	45	5.3	0	(1), (5)
Cd	dis.	<1986				20					(8)
Cd	part.	<1986				20					(8)
Cd	whole	1978	17	12	45.6	26.6	9.3	26			(2)
Cd	whole	<1981		<20	3000	<20					
Cd	whole	1981	11	19	87	42	18	44	5.3	0	(1), (5)
As	dis.	1981	11	420	1200	750	260	790	380	0	(1), (5)
As	whole	1981	11	480	1300	790	260	690	380	0	(1), (5)
As	whole	<1986				800					(8)
DDT	dis.	<1986				0.1					(8)
DDT	part.	<1986				0.1					(8)
DDT	whole	<1981				<1000					(3)
dieldrin	dis.	<1986				0.2					(8)
dieldrin	part.	<1986				0.1					(8)
dieldrin	whole	<1981	15			<1					(3)
a-BHC	dis.	<1986				9					(8)
a-BHC	part.	<1986				1					(8)
lindane	dis.	<1986				0.6					(8)
lindane	part.	<1986				0.1					(8)
toxaphene	dis.	<1986				0.4					(8)
toxaphene	part.	<1986				0.2					(8)
toxaphene	whole	<1981				<1					(3)
toxaphene	whole	1981				0.6					(4)
B(a)P	dis.	<1986				0.7					(8)
B(a)P	part.	<1986				0.3					(8)
HCB	dis.	<1986				0.04					(8)
HCB	part.	<1986				0.02					(8)
PCBs	dis.	<1986				1.4					(8)
PCBs	part.	<1986				0.6					(8)
PCBs	whole	<1981				<100					(3)
PCBs	whole	1980	7			6.36	1.3				(7)
PCBs	whole	1980	19	0.4	7.9	1.8	1.8	1.8			(6)

ND : not detected

Sample : whole = whole water; dis. = aqueous phase; part. = suspended particulate phase.

# : number of samples; SD : standard deviation; DL : detection limit;

% <DL : percent below the detection limit

1. Rossmann 1984. Particulate conc.: ppt=ng/L. Filter: 0.5 um pore size. Particulate conc. + dissolved conc. = whole water concentration.
2. Muhlbaier and Tisue 1981
3. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrate the types of values and the relative range of concentrations reported.
4. Sullivan and Armstrong 1985
5. Rossmann and Barres 1988. The number presented for "% below detection" actually represents the percent of analyses below the limit or criterion of detection. Particulate concentrations are ng/L.
6. Swackhammer and Armstrong 1987
7. Eadie *et al.* 1983
8. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models. Part. conc.: ppt=ng/L. Particulate conc. + dissolved conc. = whole water conc.

TABLE 7. CONCENTRATIONS OF CONTAMINANTS IN BOTTOM SEDIMENTS FROM LAKE MICHIGAN (ppb)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	3 cm	1975	286	1,000	153,000	40,000	41,000			3	(3)
Pb		<1981		1,000	150,000	40,000					(1)
Pb		<1984		10,000	130,000						(8)
Pb		<1986				40,000					(2)
Hg	3 cm	1975	286	20	800	107	111			0.7	(3)
Hg		<1981		20	600	100					(1)
Hg		<1984		30	380						(8)
Hg		<1986				100					(2)
Cd	3 cm	1975	286	500	2,500	900	400			66	(3)
Cd		<1981		500	2,500	1,000					(1)
Cd		<1984		50	1,800						(8)
Cd		<1986				1,000					(2)
As	3 cm	1975	286	800	153,000	10,500	16,000			0.7	(3)
As		<1984		5,000	15,000						(8)
As		<1986				11,000					(2)
tDDT	3 cm	1975	286			11.9	18.59		0.1	7	(7)
tDDT		<1981		2	300	20					(1)
tDDT		<1986				50					(2)
p,p'-DDE	3 cm	1975	286			5.43	8.44		0.1	7	(7)
dieldrin	3 cm	1975	286			0.25	0.43		0.1	52	(7)
dieldrin		<1981		<0.5	10	2					(1)
dieldrin		<1986				40					(2)
Mirex	3 cm	1975	62		ND				0.2	100	(7)
PAHs	3 cm	1978		200	6,200						(6)
a-BHC		<1936				1					(2)
lindane		<1986				0.5					(2)
B(a)P		<1983				480	246				(5)
B(a)P		<1986				500					(2)
HCB		<1986				2					(2)
PCBs	3 cm	1975	279			9.7			2	20	(7)
PCBs		<1981		100	200						(1)
PCBs		<1986				200					(2)
PCBs		1980									
OCDD		1982	1			0.96					(4)

ND : not detected
Sample : depth of surficial sediment sample
# : number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrate the types of values and the relative range of concentrations reported.
2. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models.
3. Cahill 1981. Depositional and non-depositional zones.
4. Czuczwa and Hites 1986
5. Eadie 1984
6. Helfrich and Armstrong 1986. Southern Lake Michigan.
7. Frank *et al.* 1981a. Depositional and non-depositional zones. 8. Mudroch *et al.* 1988. These numbers are a summary of concentration ranges taken from reports published between 1974 and 1984. Concentrations are from surface samples of depositional zones.

TABLE 8. CONCENTRATIONS OF CONTAMINANTS IN LAKE HURON WATER (ppt)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	dis.	1980	23	ND	81	19	26	8.9	23	71	(2), (5)
Pb	dis.	<1986				150					(1)
Pb	part.	1980	23	ND	140	50	34	41	12	4	(2), (5)
Pb	part.	<1986				50					(1)
Pb	whole	<1981				<1000					(10)
Pb	whole	1980	23	ND	110	38	35	22	34	61	(2), (5)
Hg	dis.	1980	23	ND	360	50	90	4.2	200	87	(2), (5)
Hg	dis.	<1986				7					(1)
Hg	part.	<1986				3					(1)
Hg	whole	1970-71	387	50	380	170	110		50		(6)
Hg	whole	<1981		<40	150						(10)
Hg	whole	1980	23	ND	350	60	92	11	89	61	(2), (5)
Cd	dis.	1980	23	ND	46	3.8	10	0	17	91	(2), (5)
Cd	dis.	<1986				20					(1)
Cd	part.	1980	23	ND	150	21	31	12	0.83	13	(2), (5)
Cd	part.	<1986				20					(1)
Cd	whole	<1981				<20					(10)
Cd	whole	1980	23	ND	61	16	13	15	5.5	13	(2), (5)
As	dis.	1980	23	ND	1750	240	190	250	20	22	(2), (5)
As	part.	1980	23	ND	17	8	4.6	8.6	1.4	61	(2), (5)
As	whole	1969	155	ND	700	410			100	0	(3)
As	whole	1980	23	72	53	250	120	210	14	0	(2), (5)
As	whole	<1986				700					(1)
tDDT	dis.	<1986				0.1					(1)
tDDT	part.	<1986				0.1					(1)
tDDT	whole	<1981				<4					(10)
p,p'-DDT	whole	1980	15	0.01	0.062	0.028	0.013	0.029			(7)
p,p'-DDT	whole	1981	5	0.007	0.027	0.014	0.007	0.01			(7)
p,p'-DDT	whole	1984	16		ND					100	(8)
o,p'-DDT	whole	1984	16		ND					100	(8)
p,p'-DDT	whole	1986	17		ND				0.007	100	(8)
o,p'-DDT	whole	1986	17		ND				0.007	100	(8)
p,p'-DDE	whole	1980	15	0.01	0.09	0.031	0.024	0.021			(7)
p,p'-DDE	whole	1981	5	0.006	0.019	0.013	0.005	0.012			(7)
p,p'-DDE	whole	1984	16	<0.002	0.016						(8)
p,p'-DDE	whole	1986	17	0.018	0.046	0.024			0.007	61	(8)
dieldrin	dis.	<1986				0.2					(1)
dieldrin	part.	<1986				0.1					(1)
dieldrin	whole	<1981				<1					(10)
dieldrin	whole	1984	16	0.197	0.366						(8)
dieldrin	whole	1986	17	0.202	0.688	0.368			0.007	0	(8)
a-BHC	dis.	<1986				9					(1)
a-BHC	part.	<1986				1					(1)
a-BHC	whole	1984	16	4.32	12.19						(8)
a-BHC	whole	1986	17	2.504	10.847	6.16			0.007	0	(8)
lindane	dis.	<1986				0.6					(1)
lindane	part.	<1986				0.1					(1)
lindane	whole	1984	16	0.475	0.835						(8)
lindane	whole	1986	17	0.512	1.418	0.805				0	(8)
mirex	whole	1986	17		ND				0.007	100	(8)
toxaphene	dis.	<1986				0.4					(1)

TABLE 8. CONTINUED

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
toxaphene	part.	<1986				0.2					(1)
toxaphene	whole	1980-81				1.6					(9)
B(a)P	dis.	<1986				0.07					(1)
B(a)P	part.	<1986				0.03					(1)
HCB	dis.	<1986				0.01					(1)
HCB	part.	<1986				0.01					(1)
HCB	whole	1980	15	0.003	0.019	0.009	0.005	0.007			(7)
HCB	whole	1980	5	0.02	0.1	0.04			0.01		(4)
HCB	whole	1981	5	0.002	0.007	0.005	0.002	0.004			(7)
HCB	whole	1984	16	0.003	0.032						(8)
HCB	whole	1986	17	0.018	0.073	0.033				6	(8)
PCBs	dis.	<1986				0.7					(1)
PCBs	part.	<1986				0.3					(1)
PCBs	whole	1980	15	0.282	3.232	0.929	0.837	0.572			(7)
PCBs	whole	1981	5	0.135	0.78	0.4	0.234	0.349			(7)
PCBs	whole	<1981		1	10	<100					(10)
PCBs	whole	1984	16	0.076	0.394						(8)
PCBs	whole	1986	17	0.186	2.342	0.631				0	(8)

ND : not detected
Sample : whole = whole water; dis. = aqueous phase; part. = suspended particulate phase.
# : number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models. Part. conc.: ppt=ng/L. Particulate conc. + dissolved conc. = whole water conc.
2. Rossmann 1982. Including Georgian Bay and the North Channel. Particulate conc.: ppt=ng/L. Filter: 0.5 um pore size. Particulate conc. + dissolved conc. = whole water concentration.
3. Traversy *et al.* 1975. Excluding Georgian Bay and the North Channel.
4. Oliver and Nicol 1982
5. Rossmann and Barres 1988. The number presented for "% below detection" actually represents the percent of analyses below the limit or criterion of detection. Particulate concentrations are ng/L.
6. Chau and Saitoh 1973. Excluding Georgian Bay and the North Channel.
7. Filkins and Smith 1982. Including Georgian Bay and the North Channel.
8. Stevens and Nielson in press. The 1986 results exclude Georgian Bay and the North Channel. The 1984 results are based on centrifuged samples and include Georgian Bay and the North Channel.
9. Swain 1978 as quoted in Kreis and Rice 1985
10. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrate the types of values and the relative range of concentrations reported.

TABLE 9. CONCENTRATIONS OF CONTAMINANTS IN BOTTOM SEDIMENTS FROM LAKE HURON (ppb)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	3 cm	1969	197			49,000	34,000				(6)
Pb	1-2 cm	?1969	6	81,300	151,400	123,100	23,000	132,000			(5)
Pb		<1981		50,000	150,000	50,000					(1)
Pb		<1984		3,000	151,400						(3)
Pb		<1986				70,000					(2)
Hg	3 cm	1969	197			217	160				(6)
Hg	1-2 cm	?1969	6	90	297	157	72	122			(5)
Hg		<1981		100	500	200					(1)
Hg		<1984		10	805						(3)
Hg		<1986				300					(2)
Cd	3 cm	1969	197			1,400	3,900				(6)
Cd	1-2 cm	?1969	6	1,400	2,600	2,000	450	2,000			(5)
Cd		<1981		1,000	2,000	1,500					(1)
Cd		<1984		300	4,300						(3)
Cd		<1986				1,000					(2)
As	3 cm	1969	197			1,090	2,160				(6)
As	3 cm	1969	10			2,300	1,100				(4)
As	1-2 cm	?1969	3	19,000	24,000	21,000	2,000	19,000			(5)
As		<1984		14,700	54,000						(3)
As		<1986				5,000					(2)
tDDT	3 cm	1969	174	ND	220	10.2			0.2	2.3	(11)
tDDT		<1981				<30					(1)
tDDT		<1986				40					(2)
p,p'-DDE	3 cm	1969	174	ND	21	3			0.2	6.9	(11)
DDE	3 cm	1980	9	2	15	10					(12)
DDE	3 cm	1980	5	4	28.9	20.6	9	23			(10)
dieldrin	3 cm	1969	174	ND	1.3	<0.2			0.2	94.3	(11)
dieldrin		<1981				<10					(1)
dieldrin		<1986				20					(2)
Mirex	3 cm	1969			ND					100	(11)
Mirex	3 cm	1980	9		ND					100	(12)
a-BHC	3 cm	1980	9		low				0.2	0	(12)
a-BHC		<1986				1					(2)
lindane	3 cm	1980	9		low				0.1	0	(12)
lindane		<1986				0.5					(2)
B(a)P			1			294					(8)
B(a)P		<1986				200					(2)
HCB	3 cm	1980	42	0.4	5	2					(9)
HCB	3 cm	1980	9	0.5	3.3	1.5					(12)
HCB	3 cm	1980	5	1.7	3.1	2.4	0.46	2.3			(10)
HCB		<1986				2					(2)
HCBD	3 cm	1980	9	0.04	0.1	0.08					(12)
HCBD	3 cm	1980	5	0.05	0.6	0.3	0.2	0.3			(10)
PCBs	3 cm	1969	174	3	90	13	10			0	(11)
PCBs	3 cm	1980	9	12	51	34					(12)
PCBs	3 cm	1980	5	64	390	152	121				(10)
PCBs		<1981		<10	>100	100					(1)
PCBs		<1986				100					(2)
OCDD		1975-81	4			088					(7)

ND : not detected
Sample : depth of surficial sediment sample
: number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrate the types of values and the relative range of concentrations reported.
2. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models.
3. Mudroch *et al.* 1988. These numbers are a summary of concentration ranges taken from reports published between 1974 and 1984. Concentrations are from surface samples of depositional zones.
4. Traversy *et al.* 1975
5. Kemp *et al.* 1978
6. UC 1977b. Excluding Georgian Bay and the North Channel.
7. Czuczwa and Hites 1986
8. Eadie 1984
9. Oliver and Nicol 1982. Depositional and non-depositional zones.
10. Bourbonniere *et al.* 1986. Excluding Georgian Bay and the North Channel.
11. Frank *et al.* 1979b. Excluding Georgian Bay and the North Channel. Depositional and non-depositional zones.
12. Oliver and Bourbonniere 1985. Southern Lake Huron. "Low" concentrations: all concentrations were above but close to the detection limit.

TABLE 10. CONCENTRATIONS OF CONTAMINANTS IN LAKE ERIE WATER (ppt)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	dis.	1981	11	ND	500	220	140	170		9	(2), (5)
Pb	dis.	<1986				750					(4)
Pb	part.	1981	11					190			(5)
Pb	part.	<1986				250					(4)
Pb	whole	1978-79				1,180-26,310					(1)
Pb	whole	<1981		<1,000	5,000						(7)
Pb	whole	1981	11	150	3,000	910	1,000	340		0	(2), (5)
Hg	dis.	1981	11	ND	80	34	29	24		55	(2), (5)
Hg	dis.	<1986				30					(4)
Hg	part.	1981	11					2			(5)
Hg	part.	<1986				10					(4)
Hg	whole	1970-71	170	ND	400	170	110		50		(6)
Hg	whole	1978-79				10-730					(1)
Hg	whole	<1981				<1,000					(7)
Hg	whole	1981	11	ND	14	42	44	33		27	(2), (5)
Cd	dis.	1981	11	41	120	71	27	67		0	(2), (5)
Cd	dis.	<1986				50					(4)
Cd	part.	<1986				50					(4)
Cd	whole	1978-79				370-10,660					(1)
Cd	whole	<1981				<200					(7)
Cd	whole	1981	11	39	320	98	81	72		0	(2), (5)
As	dis.	1981	11	ND	800	380	190	420		55	(2), (5)
As	part.	1981	11					87			(5)
As	whole	1969	17	ND	600	250			100	35	(3)
As	whole	1978-1979				ND-2,290					(1)
As	whole	1981	11	280	920	490	200	430		0	(2), (5)
As	whole	<1986				500					(4)
tDDT	dis.	<1986				0.1					(4)
tDDT	part.	<1986				0.1					(4)
tDDT	whole	<1981				<1					(7)
p,p'-DDT	whole	1986	21		ND				0.011	100	(8)
o,p'-DDT	whole	1986	21		ND				0.011	100	(8)
p,p'-DDE	whole	1986	21	0.028	0.096	0.053			0.011	48	(8)
dieldrin	dis.	<1986				0.3					(4)
dieldrin	part.	<1986				0.1					(4)
dieldrin	whole	<1981				<1					(7)
dieldrin	whole	1986	21	0.082	1.111	0.402			0.011	0	(8)
a-BHC	dis.	<1986				9					(4)
a-BHC	part.	<1986				1					(4)
a-BHC	whole	1986	21	2.576	6.513	3.962			0.011	0	(8)
lindane	dis.	<1986				2.0					(4)
lindane	part.	<1986				0.2					(4)
lindane	whole	1986	21	0.581	2.554	1.075			0.011	0	(8)
mirex	whole	1986	21		ND				0.011	100	(8)
toxaphene	dis.	<1986				0.4					(4)
toxaphene	part.	<1986				0.2					(4)
toxaphene	whole	1981				0.7					(9)
B(a)P	dis.	<1986				0.2					(4)
B(a)P	part.	<1986				0.1					(4)
HCB	dis.	<1986				0.04					(4)
HCB	part.	<1986				0.02					(4)
HCB	whole	1986	21	0.025	0.26	0.078			0.011	24	(8)

TABLE 10. CONTINUED

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
PCBs	dis.	<1986				0.7					(4)
PCBs	part.	<1986				0.3					(4)
PCBs	whole	<1981		1	10	<100					(7)
PCBs	whole	1986	21	0.341	3.513	1.378			0.24	0	(8)

ND : not detected
Sample : whole = whole water; dis. = aqueous phase; part. = suspended particulate phase.
# : number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Rathke 1984. The range represents the mean concentrations for the 2nd to 4th quarters of 1978 and 1979 along the south shore.
2. Rossmann 1984. Particulate conc.: ppt=ng/L. Filter: 0.5 um pore size. Particulate conc. + dissolved conc. = whole water concentration.
3. Traversy *et al.* 1975.
4. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models. Part. conc.: ppt=ng/L. Particulate conc. + dissolved conc. = whole water conc.
5. Rossmann and Barres 1988. The number presented for "% below detection" actually represents the percent of analyses below the limit or criterion of detection. Particulate concentrations are ng/L.
6. Chau and Saitoh 1973.
7. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrate the types of values and the relative range of concentrations reported.
8. Stevens and Nielson in press.
9. Sullivan and Armstrong 1985

TABLE 11. CONCENTRATIONS OF CONTAMINANTS IN BOTTOM SEDIMENTS FROM LAKE ERIE (ppb)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	3 cm	1971	258	9,000	299,000	87,000	50,000				(5)
Pb	1 cm	1971	6	83,000	146,000	107,000	23,000	100,000			(11)
Pb	10 cm	1979		<50,000	>140,000						(13)
Pb		<1981		<50,000	>150,000						(1)
Pb		<1984		6,000	299,000						(3)
Pb		<1986				100,000					(2)
Hg	3 cm	1971	258	8	2,929	578	554				(5)
Hg	1 cm	1971	6	330	1,430	860	340	850			(11)
Hg	10 cm	1979		<300	<2,000						(13)
Hg		<1981		<50	2,000						(1)
Hg		<1984		45	4,800						(3)
Hg		<1986				500					(2)
Cd	3 cm	1971	258	100	10,800	2,400	1,500				(5)
Cd	1 cm	1971	6	2,500	4,500	3,500	720	3,500			(11)
Cd	10 cm	1979		<3,000	>4,000						(13)
Cd		<1981				<8,000					(1)
Cd		<1984		800	13,700						(3)
Cd		<1986				1,000					(2)
As	3 cm	1971	10	2,000	4,000	3,200	1,100	3,200			(4)
As	3 cm	1971	258	200	60,000	1,300	4,300				(5)
As		<1984		450	12,300						(3)
tDDT	3 cm	1971	259	0.6	322	27.9	32.6		0.1-0.2		(14)
tDDT		<1981		20	30						(1)
tDDT		<1986				30					(2)
p,p'-DDE	3 cm	1971	259	0.2	136	8.2	11.4		0.1-0.2	0	(14)
p,p'-DDE	3 cm	1982	46	2.6	17	3.8-8					(12)
DDE	3 cm	1982	5	5.7	21	10.7	5.4	9.8			(10)
dieldrin	3 cm	1971	259	ND	5	1.2	0.9		0.2	14	(14)
dieldrin		<1981				<3					(1)
dieldrin		<1986				20					(2)
Mirex	3 cm	1982	46		ND					100	(12)
Mirex	3 cm	1982	5		ND					100	(10)
a-BHC	3 cm	1982	46		l[illegible]				0.2	0	(12)
a-BHC		<1986				2					(2)
lindane	3 cm	1982	46		low				0.1	0	(12)
lindane		<1986				1					(2)
B(a)P			3			255	152				(8)
B(a)P		<1986				200					(2)
HCB	3 cm	1980	5	0.7	12	3					(9)
HCB	3 cm	1982	5	2.5	20	7.6	6.8	2.8			(10)
HCB	3 cm	1982	46	1.2	17	2.4-9.1					(12)
HCB		<1986				4					(2)
HCBD	3 cm	1982	5	0.1	2.4	0.86	0.84	0.5			(10)
HCBD	3 cm	1982	46	0.1	3.2	0.2-1.6					(12)
PCBs	3 cm	1971	231	4	800	95	114				(14)
PCBs		<1981		<10	>100	100					(1)
PCBs	3 cm	1982	46	37	660	91-300					(12)
PCBs	3 cm	1982	5	150	1099	428	355.3	242.2			(10)
PCBs		<1986				60					(2)
OCDD		1981-83	2	1.7	2.0						(7)

ND : not detected
Sample : depth of surficial sediment sample
# : number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrate the types of values and the relative range of concentrations reported.
2. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models.
3. Mudroch *et al.* 1988. These numbers are a summary of concentration ranges taken from reports published between 1974 and 1984. Concentrations are from surface samples of depositional zones.
4. Traversy *et al.* 1975
5. Thomas and Mudroch 1979.
7. Czuczwa and Hites 1986
8. Eadie 1984. Adjacent to Raisin River in the Western Basin.
9. Oliver and Nicol 1982. Depositional and non-depositional zones.
10. Bourbonniere *et al.* 1986. Excluding Georgian Bay and the North Channel.
11. Kemp and Thomas 1976b
12. Oliver and Bourbonniere 1985. Mean concentrations were given for the Western, Central and Eastern zones.
13. Rathke 1984
14. Frank *et al.* 1977. Depositional and non-depositional zones.

TABLE 12. CONCENTRATIONS OF CONTAMINANTS IN NIAGARA RIVER WATER (ppt)

Chemical	Sample	Place	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	whole	UNR	1979	168			1,000				23	(4)
Pb	whole	NOTL	1976-83	394					<1,000-2,000			(2)
Pb	whole	FE	1985				1,000	1,000				(7)
Pb	whole	NOTL	1985				1,000	1,000				(7)
Pb	whole		<1986				1,000					(5)
Pb	whole	FE	1986-87	48	800	2,100	1,400				29	(1)
Pb	whole	NOTL	1986-87	45	900	2,600	1,600				27	(1)
Hg	whole	UNR	1979	144			10				85	(4)
Hg	whole	NOTL	1979-82	202					<50			(2)
Hg	whole	NOTL	1983	50					<20			(2)
Hg	whole	FE	1985				<20					(7)
Hg	whole	NOTL	1985				<20					(7)
Hg	whole		<1986				70					(5)
Cd	whole	UNR	1979	165			<1,000				98	(4)
Cd	whole	NOTL	1976-83	394					<1,000			(2)
Cd	whole	FE	1985				<1,000					(7)
Cd	whole	NOTL	1985				<1,000					(7)
Cd	whole		<1986				100					(5)
Cd	whole	FE	1986-87	48	90	120	100				58	(1)
Cd	whole	NOTL	1986-87	45	100	170	130				56	(1)
As	whole	UNR	1979	94			4,000				0	(4)
As	whole	NOTL	1980-83	211					500-1,100			(2)
As	whole	FE	1985				500	200				(7)
As	whole	NOTL	1985				700	400				(7)
As	whole		<1986				500					(5)
As	whole	FE	1986-87	49	590	640	610				0	(1)
As	whole	NOTL	1986-87	48	690	840	760				0	(1)
tDDT	whole		<1986				0.4					(5)
p,p'-DDT	whole	UNR	1979	72			<1			1	99	(4)
p,p'-DDT	whole	NOTL	1980-82	75			0.2	0.5	<0.1		60	(4)
p,p'-DDT	dis.	FE	1981				0.015					(4)
p,p'-DDT	dis.	NOTL	1981				0.02					(4)
p,p'-DDT	dis.		1981		0.01	0.05						(10)
p,p'-DDT	whole	NOTL	1985-86	43	1.2	20.1	11.2	7.7				(8)
p,p'-DDT	part.	FE	1986-87	45	0.14	0.21	0.17	0.74			20	(1)
p,p'-DDT	part.	NOTL	1986-87	42	0.026	0.05	0.036	0.64			86	(1)
p,p'-DDE	whole	UNR	1979	72			<1			1	94	(4)
p,p'-DDE	whole	NOTL	1980-82	75			0.3	0.5	0.1		39	(4)
p,p'-DDE	dis.	FE	1981				ND					(4)
p,p'-DDE	dis.	NOTL	1981				0.015					(4)
p,p'-DDE	whole	NOTL	1981	5		ND				0.5	100	(9)
p,p'-DDE	whole	NOTL	1985-86	43	0.1	33.5	2.9	8.5				(8)
p,p'-DDE	part.	FE	1986-87	45	0.32	0.48	0.39	0.75			0	(1)
p,p'-DDE	part.	NOTL	1986-87	42	0.044	0.052	0.048	0.31			45	(1)
dieldrin	whole	UNR	1979	72			<1			1	68	(4)

TABLE 12. CONTINUED

Chemical	Sample	Place	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
dieldrin	whole	NOTL	1980-82	75			0.6	0.3	0.6		7	(4)
dieldrin	dis.	FE	1981				0.26					(4)
dieldrin	dis.	NOTL	1981				0.27					(4)
dieldrin	dis.		1981		0.2	0.35						(10)
dieldrin	whole	NOTL	1981	5	ND	0.9				0.5	60	(9)
dieldrin	whole	NOTL	1985-86	43	0.3	8.2	2.9	4.6				(8)
dieldrin	whole		<1986				0.6					(5)
dieldrin	dis.	FE	1986-87	44	0.3	0.34	0.32	0.3			4	(1)
dieldrin	dis.	NOTL	1986-87	38	0.28	0.34	0.31	0.36			16	(1)
dieldrin	part.	FE	1986-87	45	0.013	0.029	0.02	1.2			82	(1)
dieldrin	part.	NOTL	1986-87	42	0.015	0.023	0.019	0.46			81	(1)
a-BHC	whole	UNR	1979	72			7			1	0	(4)
a-BHC	whole	NOTL	1980-82	75			10.5	5.2	9.7		0	(4)
a-BHC	dis.	FE	1981				2.89					(4)
a-BHC	dis.	NOTL	1981				5.5					(4)
a-BHC	dis.		1981		<1	8						(10)
a-BHC	whole		1981	5	ND	7				0.5	20	(9)
a-BHC	whole	LO	1982	244	1	84						(11)
a-BHC	whole	NOTL	1985-86	43	0.5	3.6	1.7	1.1				(8)
a-BHC	whole		<1986				10					(5)
a-BHC	dis.	FE	1986-87	44	2.71	2.33	2.51	0.3			2	(1)
a-BHC	dis.	NOTL	1986-87	38	2.24	2.65	2.44	0.31			3	(1)
a-BHC	part.	NOTL	1986-87	42	0.0096	0.043	0.022	1.65			76	(1)
lindane	whole	UNR	1979	72			1			1	16	(4)
lindane	whole	NOTL	1980-82	75			2.1	1.5	1.8		1	(4)
lindane	dis.	FE	1981				0.59					(4)
lindane	dis.	NOTL	1981				1.5					(4)
lindane	dis.		1981		0.5	1.8						(10)
lindane	whole		1981	5	ND	0.9				0.5	40	(9)
lindane	whole	LO	1982	245	<1	28					3	(11)
lindane	whole		<1986				2					(5)
lindane	dis.	FE	1986-87	44	0.6	0.68	0.64	0.25			4	(1)
lindane	dis.	NOTL	1986-87	38	0.6	0.7	0.65	0.28			8	(1)
Mirex	whole	NOTL	1980-82	75			<0.1		<0.1		99	(4)
Mirex	whole		<1986				0.3					(5)
Mirex	part.	NOTL	1986-87	42	0.016	0.03	0.022	0.74			83	(1)
Toxaphene	whole		<1986				0.6					(5)
B(a)P	whole		<1986				0.3					(5)
B(a)P	part.	NOTL	1986-87	42	1.05	2.28	1.59	0.63			88	(1)
TeCB	dis.	NOTL	1986-87	38	0.56	0.92	0.72	0.82			11	(1)
TeCB	part.	NOTL	1986-87	42	0.19	0.45	0.3	1.29			7	(1)
HCB	whole	UNR	1979	72			<1			1	97	(4)
HCB	whole	NOTL	1980-82	75			0.8	0.9	0.5		5	(4)
HCB	whole	NOTL	1981	5		ND				0.5	100	(9)
HCB	whole	LO	1982	245	<1	8					88	(11)
HCB	whole	NOTL	1985-86	43	0.1	4.3	1.5	1.5				(8)

TABLE 12. CONTINUED

Chemical	Sample	Place	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
HCB	whole		<1986				0.4					(5)
HCB	dis.	NOTL	1986-87	38	0.11	0.13	0.12	0.36			8	(1)
HCB	part.	NOTL	1986-87	42	0.11	0.23	0.17	1.11			28	(1)
HCBD	whole	NOTL	1985-86	43	0.1	0.2	0.2	0.1				(8)
HCBD	dis.	NOTL	1986-87	38	0.09	0.12	0.11	0.45			29	(1)
HCBD	part.	NOTL	1986-87	42	0.035	0.11	0.066	1.45			60	(1)
PCBs	whole	UNR	1979	72			5			20	81	(4)
PCBs	whole	NOTL	1980-82	75			19.9	34.7	11		3	(4)
PCBs	dis.	FE	1981				0.26					(4)
PCBs	dis.	NOTL	1981				0.8					(4)
PCBs	dis.		1981		0.2	1.3						(10)
PCBs	whole	NOTL	1981	5	ND	39				5	60	(9)
PCBs	whole		<1986				10					(5)
PCBs	dis.	FE	1986-87	44	2.57	3.26	2.9	0.09			93	(1)
PCBs	part.	FE	1986-87	45	0.88	1.14	1.0	0.49			36	(1)
PCBs	part.	NOTL	1986-87	42	1.42	1.91	1.66	0.54			2	(1)
TCDD	dis.		1984	6		ND					100	(3)
TCDD	part.		1984	8		ND					100	(3)
PnCDD	dis.		1984	6	ND	0.3					83	(3)
PnCDD	part.		1984	8	ND	76					75	(3)
HxCDD	dis.		1984	6	ND	0.4					67	(3)
HxCDD	part.		1984	8	ND	177					38	(3)
HpCDD	dis.		1984	6	ND	1.4					83	(3)
HpCDD	part.		1984	8	ND	238					38	(3)
OCDD	dis.		1984	6	ND	3.6					17	(3)
OCDD	part.		1984	8	ND	228					12	(3)
TCDF	dis.		1984	6	ND	156					83	(3)
TCDF	part.		1984	8	ND	412					50	(3)
PnCDF	dis.		1984	6	ND	317					33	(3)
PnCDF	part.		1984	8	ND	300					12	(3)
HxCDF	dis.		1984	6	ND	14					67	(3)
HxCDF	part.		1984	8	ND	495					25	(3)
HpCDF	dis.		1984	6	ND	1.5					83	(3)
HpCDF	part.		1984	8	ND	2,450					25	(3)
OCDF	dis.		1984	6	ND	0.5					33	(3)
OCDF	part.		1984	8	2.2	2,530					0	(3)

ND : not detected
Sample : whole = whole water; dis. = aqueous phase; part. = suspended particulate phase.
Place : testing place
# : number of samples
SD : standard deviation DL : detection limit
% <DL : percent below the detection limit
FE : Fort Erie
NOTL : Niagara-on-the-Lake
LNR : Lower Niagara River, north of Niagara Falls.
UNR : Upper Niagara River, south of Niagara Falls
LO : Samples taken from the Niagara River plume in Lake Ontario.

1. DOE, USEPA, MOE & NYDEC 1988. Minimum and maximum values represent 90% confidence intervals. Particulate concentration: Equivalent water concentration for particulate phase calculated as product of mean contaminant concentration on particulate and mean suspended sediment concentrations. Particulate conc. + dissolved concentration = whole water concentration. ND: not detected or not analysed for.
2. Kuntz 1988b. Weekly samples.
3. Hallett and Brooksbank 1986
4. Kuntz 1984b. Weekly sampling.
5. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models.
6. DOE and MOE 1981.
7. Kuntz and Biberhofer 1986
8. Maguire and Tkacz 1988
9. Maguire *et al.* 1983. Samples taken at 5 stations along the river in July, 1981.
10. McCrea *et al.* 1985. Concentrations listed here are approximations.
11. Fox and Carey 1985. Samples from the Niagara River plume in Lake Ontario.
12. Warry and Chan 1981a

TABLE 13. CONCENTRATIONS OF CONTAMINANTS IN SUSPENDED SEDIMENTS FROM THE NIAGARA RIVER (ppb)

Chemical	Sample	Place	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	part.*	NOTL	1978	13			80,000	28,600				(3)
Pb	part.*	NOTL	1979-80	35			58,000	18,900				(3)
Pb	part.*	NOTL	1981	29			93,000	61,000				(1)
Pb	part.*	NOTL	1982	27			93,000	57,000				(1)
Hg	part.*	FE	1981				83					(1)
Hg	part.*	NOTL	1981				333					(1)
Cd	part.*	NOTL	1978	13			2,400	800				(3)
Cd	part.*	NOTL	1979-80	35			2,400	1,300				(3)
Cd	part.*	NOTL	1981	14			7,300	4,000				(1)
Cd	part.*	NOTL	1982	27			4,700	5,200				(1)
As	part.*	FE	1981				9,900					(1)
As	part.*	NOTL	1981				12,100					(1)
tDDT	part.*	NOTL	1979-80	41			30.4	16.3			0	(2)
p,p'-DDT	part.*	NOTL	1979-81	70			11	12	6		14	(1)
p,p'-DDT	part.*	NOTL	1979-80	41			10	10			20	(2)
p,p'-DDT	part.*	FE	1981				1					(1)
p,p'-DDT	part.*	NOTL	1981				25					(1)
p,p'-DDE	part.*	NOTL	1979-81	70			23	23	18		8	(1)
p,p'-DDE	part.*	NOTL	1979-80	41			24	12			7	(2)
p,p'-DDE	part.*	FE	1981				21					(1)
p,p'-DDE	part.*	NOTL	1981				9					(1)
dieldrin	part.*	NOTL	1979-81	70			4	3	4		20	(1)
dieldrin	part.*	NOTL	1979-80	41			5	3			36	(2)
dieldrin	part.*	FE	1981				9					(1)
dieldrin	part.*	NOTL	1981				6					(1)
a-BHC	part.*	NOTL	1979-81	70			12	23	4		25	(1)
a-BHC	part.*	FE	1981				9					(1)
a-BHC	part.*	NOTL	1981				12					(1)
lindane	part.*	NOTL	1979-81	70			2	4	<1		67	(1)
lindane	part.*	NOTL	1979-80	41			3.7	3.3			83	(2)
Mirex	part.*	NOTL	1979-81	70			12	32	5		24	(1)
Mirex	part.*	NOTL	1979-80	41			19.4	49.5			34	(2)
Mirex	part.*	FE	1981				ND					(1)
Mirex	part.*	NOTL	1981				1					(1)
B(a)P	part.*	NOTL	?1980		190	20,000						(1)
HCB	part.*	NOTL	1979-81	70			124	320	49		0	(1)
HCB	part.*	FE	1981				1					(1)
HCB	part.*	NOTL	1981				73					(1)
PCBs	part.*	NOTL	1979-81	70			718	597	500		0	(1)
PCBs	part.*	NOTL	1979-80	41			961	2,196			0	(2)

TABLE 13. CONTINUED

Chemical	Sample	Place	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
PCBs	part.*	FE	1981				ND					(1)
PCBs	part.*	NOTL	1981				367					(1)

ND : not detected
Sample : whole = whole water; dis. = aqueous phase; part. = suspended particulate phase.
Place : testing place
: number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit
FE : Fort Erie
NOTL : Niagara-on-the-Lake
part.* : Particulate concentrations are in ng/g (ppb).

1. Kuntz 1984b. Based on weekly sampling.
2. Warry and Chan 1981
3. DOE and MOE 1981.

TABLE 14. CONCENTRATIONS OF CONTAMINANTS IN BOTTOM SEDIMENTS FROM THE NIAGARA RIVER (ppb)

Chemical	Sample	Place	Testing Date	#	Min	Max	Mean	SD	Median	% <DL	Ref.
Pb	3 cm	UNR	1979	15	4,000	200,000			11,000	0	(2)
Pb	3 cm	LNR	1979	9	6,000	60,000			16,000	0	(2)
Pb	2.54 cm		1981	16	9,000	767,000	98,000	180,000			(1)
Hg	3 cm	UNR	1979	15	<10	670			90	7	(2)
Hg	3 cm	LNR	1979	9	30	3,200			340	0	(2)
Hg	2.54 cm		1981	16	20	2,450	607	754			(1)
Cd	3 cm	UNR	1979	15	<400	880			<400	60	(2)
Cd	3 cm	LNR	1979	9	<400	880			650	11	(2)
Cd	2.54 cm		1981	16	<100	19,000	2,200	4,400			(1)
As	3 cm	UNR	1979	15	1,900	14,000			3,300	0	(2)
As	3 cm	LNR	1979	9	1,500	8,200			3,500	0	(2)
As	2.54 cm		1981	16	3,000	20,000	7,800	5,100			(1)
tDDT	3 cm	UNR	1979	15	1	24			6	0	(2)
tDDT	3 cm	LNR	1979	8	4	190			10	0	(2)
p,p'-DDT	3 cm	UNR	1979	15		ND				100	(2)
p,p'-DDT	3 cm	LNR	1979	8	ND	74			ND	75	(2)
p,p'-DDT	2.54 cm		1981	16	<1	73			<1		(1)
p,p'-DDE	3 cm	UNR	1979	15	1	19			3	0	(2)
p,p'-DDE	3 cm	LNR	1979	8	4	36			9	0	(2)
p,p'-DDE	2.54 cm		1981	16	<1	280			2.5		(1)
dieldrin	3 cm	UNR	1979	15	ND	6			ND	67	(2)
dieldrin	3 cm	LNR	1979	7	ND	26			5	28	(2)
dieldrin	2.54 cm		1981	16	<1	10			<1		(1)
Mirex	3 cm	UNR	1979	15	ND	18			5	40	(2)
Mirex	3 cm	LNR	1979	8	ND	640			5	38	(2)
Mirex	2.54 cm		1981	16	<1	890			<1		(1)
a-BHC	3 cm	UNR	1979	15	ND	1			ND	93	(2)
a-BHC	3 cm	LNR	1979	8	ND	640				50	(2)
a-BHC	2.54 cm		1981	16	<1	2,260			2		(1)
lindane	3 cm	UNR	1979	14		ND				100	(2)
lindane	3 cm	LNR	1979	8	ND	20			ND	88	(2)
lindane	2.54 cm		1981	16	<1	87			<1		(1)
HCB	3 cm	UNR	1979	15	ND	22			ND	93	(2)
HCB	3 cm	LNR	1979	8	1	250			32	0	(2)
HCB	2.54 cm		1981	16	<1	110			2		(1)
PCBs	3 cm	UNR	1979	13	ND	960			220	8	(2)
PCBs	3 cm	LNR	1979	8	66	2,700			280	0	(2)
PCBs	2.54 cm		1981	16	<10	17,900			210		(1)

ND : not detected
Sample : depth of surficial sediment sample
Place : testing place
# : number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit
LNR : Lower Niagara River, north of Niagara Falls.
UNR : Upper Niagara River, south of Niagara Falls

1. Kuntz 1984b.
2. DOE and MOE 1981.

TABLE 15. CONCENTRATIONS OF CONTAMINANTS IN LAKE ONTARIO WATER (ppt)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	dis.	1985	22					ND		91	(5)
Pb	dis.	<1986				300					(11)
Pb	part.	1978	19	78	970						(2)
Pb	part.	1985	22					28		41	(5)
Pb	part.	<1986				100					(11)
Pb	whole	1979	532		3,000	310-400			500	67	(1)
Pb	whole	<1981		1,000	5,000						(12)
Pb	whole	1982	55			<500					(4)
Pb	whole	1985	22					40			(5)
Hg	dis.	1985	22					11		96	(5)
Hg	dis.	<1986				20					(11)
Hg	part.	1985	22					ND			(5)
Hg	part.	<1986				5					(11)
Hg	whole	1970-71	132	ND	300	130	70				(6)
Hg	whole	1979	528		160	25-27			50	98	(1)
Hg	whole	<1981				<200					
Hg	whole	1982	55			<10					(4)
Hg	whole	1985	22					10		73	(5)
Cd	dis.	1985	22					24		41	(5)
Cd	dis.	<1986				60					(11)
Cd	part.	1978	15	4.4	58						(2)
Cd	part.	1985	22					69		0	(5)
Cd	part.	<1986				60					(11)
Cd	whole	1979	532		300	50-60			100	92	(1)
Cd	whole	<1981		<1,000	15,000						(12)
Cd	whole	1982	55			<200					(4)
Cd	whole	1985	22					96			(5)
As	dis.	1985	22					490		9	(5)
As	part.	1985	22					24		86	(5)
As	whole	?1968	24	600	1,200	910			100	0	(3)
As	whole	1979	525		1,200	570-720			100	0.2	(1)
As	whole	1982	55			980					(4)
As	whole	1985	22					500			(5)
As	whole	<1986				500					(11)
tDDT	dis.	<1986				0.1					(11)
tDDT	part.	<1986				0.1					(11)
tDDT	whole	<1981		<10	60	35					(6)
tDDT	whole	1983	14	0.069	0.271	0.144	0.069	0.124			(10)
p,p'-DDT	whole	1986	31		ND				0.011	100	(8)
o,p'-DDT	whole	1986	31		ND				0.011	100	(8)
p,p'-DDE	whole	1986	31	0.023	0.139	0.053			0.011	6	(8)
dieldrin	dis.	<1986				0.3					(11)
dieldrin	part.	<1986				0.1					(11)
dieldrin	whole	<1981		1	10	4					(12)
dieldrin	whole	1983	14	0.259	0.631	0.405	0.14	0.48			(10)
dieldrin	whole	1986	31	0.075	0.514	0.331			0.011	0	(8)
a-BHC	dis.	<1986				6.0					(11)
a-BHC	part.	<1986				1.0					(11)
a-BHC	whole	1983	14	4.36	8.81	6.68	1.28	6.86			(10)
a-BHC	whole	1986	31	1.173	5.919	4.115			0.011	0	(8)
lindane	dis.	<1986				2.0					(11)
lindane	part.	<1986				0.2					(11)
lindane	whole	1983	14	0.806	1.85	1.3	0.34	1.26			(10)
lindane	whole	1986	31	0.311	2.276	1.313			0.011	0	(8)

TABLE 15. CONTINUED

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Mirex	dis.	<1986			0.03						(11)
Mirex	part.	<1986			0.03						(11)
Mirex	whole	1983	14		ND					10	(10)
Mirex	whole	1986	31		ND				0.011	100	(8)
toxaphene	dis.	<1986				0.4					(11)
toxaphene	part.	<1986				0.2					(11)
toxaphene	whole	1981				0.6					(9)
toxaphene	whole	1983	14		ND					100	(10)
B(a)P	dis.	<1986				0.2					(11)
B(a)P	part.	<1986				0.1					(11)
HCB	dis.	<1986				0.04					(11)
HCB	part.	<1986				0.02					(11)
HCB	whole	1980	5	0.02	0.1	0.06			0.01		(7)
HCB	whole	1983	14	0.017	0.103	0.052		0.042		0	(10)
HCB	whole	1986	31	0.02	0.113	0.063			0.011	0	(8)
PCBs	dis.	<1986				0.6					(11)
PCBs	part.	<1986				0.3					(11)
PCBs	whole	<1981		2	50						(12)
PCBs	whole	1983	14	0.32	3.1	0.95	0.71	0.78			(10)
PCBs	whole	1986	31	0.484	5.189	1.41			0.24	0	(8)

ND : not detected
Sample : whole = whole water; dis. = aqueous phase; part. = suspended particulate phase.
# : number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Neilson 1983. The range represents the mean concentrations for 3 cruises.
2. Nriagu *et al.* 1980. Particulate conc.: ppt=ng/L.
3. Traversy *et al.* 1975.
4. Stevens 1987. Offshore waters.
5. Rossmann and Barres 1988. The number presented for "% below detection" actually represents the percent of analyses below the limit or criterion of detection. Particulate concentrations are ng/L.
6. Chau and Saitoh 1973.
7. Oliver and Nicol 1982
8. Stevens and Neilson in press.
9. Sullivan and Armstrong 1985
10. Biberhofer and Stevens 1987
11. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models. Part. conc.: ppt=ng/L. Particulate conc. + dissolved conc. = whole water conc.
12. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrate the types of values and the relative range of concentrations reported.

TABLE 16. CONCENTRATIONS OF CONTAMINANTS IN BOTTOM SEDIMENTS FROM LAKE ONTARIO (ppb)

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
Pb	3 cm	1968	275	4,000	287,000	107,000	65,000				(5)
Pb	1 cm	?1968	5	176,000	285,000	220,000	36,000	216,000			(11)
Pb		<1981		<50,000	>150,000						(1)
Pb		<1984		7,000	285,000						(3)
Pb		<1986				100,00					(2)
Hg	3 cm	1968	275	25	2,100	651	511				(5)
Hg	1 cm	?1968	5	540	3,950	2,350	130	2,650			(11)
Hg		<1981		25	3,900						(1)
Hg		<1984		140	3,950						(3)
Hg		<1986				800					(2)
Cd	3 cm	1968	275	100	20,600	2,500	1,900				(5)
Cd	1 cm	?1968	5	3,700	6,200	5,100	320	5,100			(11)
Cd		<1984		100	6,200						(3)
Cd		<1986				1,000					(2)
As	3 cm	1968	275	200	22,500	3,300	4,700				(5)
As	3 cm	?1968	8	1,500	14,000	4,100	3,800	2,800			(4)
As		<1984		200	17,000						(3)
tDDT	3 cm	1968	229	0.5	218	42.8	42.4		0.4	0	(14)
tDDT		<1981				<50					(1)
tDDT		<1986				50					(2)
p,p'-DDE	3 cm	1968	229	0.5	70	12.7	12.5		0.1	0	(14)
DDE	3 cm	1981	6	26.8	130	82	42	86			(10)
dieldrin	3 cm	1968	229	ND	6.7	0.6			0.1	61	(14)
dieldrin		<1981				<3					(1)
dieldrin		<1986				10					(2)
Mirex	3 cm	1968	229	ND	40	7.5	8.3		1	67	(12)
Mirex		1980	8	Tr	62						(15)
Mirex	3 cm	1981	35	3	65	33	16				(13)
Mirex	3 cm	1981	6	45.7	110	86	25	95.5			(10)
Mirex		<1986				50					
a-BHC		<1986				2					(2)
lindane		<1986				5					(2)
B(a)P			1			306					(8)
B(a)P		<1986				300					(2)
HCB		1980	12	7.6	89						(15)
HCB	3 cm	1980	11	9	320	97					(9)
HCB	3 cm	1981	35	16	250	112	63				(13)
HCB	3 cm	1981	6	150	380	226	73	205			(10)
HCB	2 cm	1981	9	62	840	220	230			0	(16)
HCB		<1986				10					(2)
HCBD		1980	4	Tr	8.7						
HCBD	3 cm	1981	6	24	45	34	7	34			(10)
HCBD	2 cm	1981	9	12	120	35	32			0	(16)
PCBs	3 cm	1968	229	ND	280	57	56		5	4	(14)
PCBs		<1981		30	100	80					(1)
PCBs	3 cm	1981	35	200	1200	606	256				(13)
PCBs	3 cm	1981	6	630	1,500	844	420	975			(10)
PCBs	2 cm	1981	9	260	840	570	220			0	(16)
PCBs		<1986				100					(2)

TABLE 16. CONTINUED

Chemical	Sample	Testing Date	#	Min	Max	Mean	SD	Median	DL	% <DL	Ref.
OCDD		1983	1			4.8					(7)
TCDD	3 cm	1987	5	ND	0.004					80	(6)

Tr: trace abundance
ND : not detected
Sample : depth of surficial sediment sample
# : number of samples
SD : standard deviation
DL : detection limit
% <DL : percent below the detection limit

1. Sonzogni and Simmons 1981. Typical concentration range. These values are designed only to illustrates the types of values and the relative range of concentrations reported.
2. Strachan and Eisenreich 1988. Mean value based on assessment of historical data up to 1985-86. These values were used in mass balance models.
3. Mudroch *et al.* 1988. These numbers are a summary of concentration ranges taken from reports published between 1974 and 1984. Concentrations are from surface samples of depostitional zones.
4. Traversy *et al.* 1975. Depositional and non-depositional zones.
5. Thomas and Mudroch 1979. Depositional and non-depositional zones.
6. Onuska *et al.* 1983. Western Lake Ontario.
7. Czuczwa and Hites 1986
8. Eadie 1984
9. Oliver and Nicol 1982. Depositional and non-depositional zones.
10. Bourbonniere *et al.* 1986.
11. Kemp and Thomas 1976b
12. Holdrinet et al 1978. Depositional and non-depositional zones.
13. Oliver *et al.* 1987. Depositional zones.
14. Frank *et al.* 1979a. Depositional and non-depositional zones.
15. Kaminsky *et al.* 1983. Southwestern Lake Ontario.
16. Fox *et al.* 1983. Southwestern Lake Ontario.

TOXIC CHEMICALS IN THE GREAT LAKES AND ASSOCIATED EFFECTS

VOLUME I PART 2

CONCENTRATIONS OF CONTAMINANTS IN AQUATIC BIOTA

EXECUTIVE SUMMARY

This part of the report discusses concentrations of toxic chemicals in aquatic biota, emphasising fish. It provides a broad perspective on spatial and temporal trends of toxic chemicals in subvertebrate biota and fish.

There are only a few monitoring programs that provide information on spatial and temporal trends of contaminants in subvertebrate biota. These include monitoring programs on organisms such as net plankton, *Mysis* and *Pontoporeia*. The results have shown that concentrations of cadmium, lead, mercury and selenium are highest in organisms from Lakes Huron and Superior. However, levels of PCBs and organochlorine pesticides are highest in organisms from Lake Ontario. No general conclusions can be drawn about temporal trends in these aquatic biota because of differences in sampling and analytical reporting procedures for samples from Lake Ontario and because of insufficient data from the other lakes.

Fish are excellent biomonitors of ecosystem health. Three programs have comprehensively assessed the concentrations of contaminants in fish. These are the open-lake fish contaminants program (conducted by the Department of Fisheries and Oceans in Canada and by the U.S. Fish and Wildlife Service and the Environmental Protection Agency), the Ontario Ministry of the Environment's nearshore juvenile fish contaminants surveillance program and the Ontario Ministry of the Environment's sport fish testing program.

Concentrations of many contaminants in fish decreased between the early or mid 1970s and the early 1980s. In many cases, concentrations have equilibrated since then. The decrease in concentrations reflects improved industrial practices, more stringent regulations and bans or restrictions on the manufacture or use of many organochlorines. These actions reduced new inputs of organochlorine pesticides to the environment. The equilibrium reached in the early 1980s probably reflects the inputs from remaining point sources (e.g., sewage treatment plants), cycling of contaminants within the aquatic ecosystem, re-mobilisation of sediments, as well as continued inputs to the Great Lakes from atmospheric deposition and leaking hazardous waste sites.

Concentrations of total PCBs are higher in fish from Lake Ontario than the other Great Lakes. They decreased in the 1970s and have now reached an equilibrium. Despite the reduction in levels, most concentrations are still above the GLWQA specific objective of 0.01 ppm for whole fish.

Mirex is found in Lake Ontario, the Niagara River and the St. Lawrence River. Concentrations fell significantly after a ban on its production and use in the mid 1970s. Since then, an equilibrium has been reached. The GLWQA specific objective is "substantially absent", so detectable concentrations reported exceed the objective.

Hexachlorobenzene is found in fish throughout the Great Lakes although it has not been detected in spottail shiners from Lakes Superior and Erie. The highest HCB concentrations in spottail shiners are in samples from Sarnia.

Concentrations of dieldrin in fish have not fallen as rapidly as concentrations of other organochlorines. The highest level was found in 1984 in lake trout from Lake Ontario. Concentrations in lake trout from Lakes Ontario and Superior have decreased but have varied from year to year in fish from Lake Huron.

Concentrations of DDT and metabolites have fallen in whole lake trout from Lakes Michigan and Ontario while they have remained constant in samples from Lakes Superior and Huron.

Dioxins and furans are widely distributed throughout the ecosystem. Fish from Saginaw Bay, Lake Huron have the highest concentrations. Based on limited data, concentrations in fish from Lake Ontario have remained relatively constant.

Concentrations of toxaphene are highest in fish from Lake Superior. Levels may be falling faster in fish from Lake Ontario than in fish from Lake Superior. The most important source of this chemical is atmospheric deposition.

Levels of mercury in fish have fallen significantly since the closure of the chlor-alkali plants on the Great Lakes. However, mercury concentrations in fish from Lake Huron have varied from year to year. Other heavy metals have been detected in fish, including arsenic, selenium and zinc.

Several sets of guidelines have been developed for concentrations of contaminants in fish. These include the specific objectives of the GLWQA and those established by various health agencies. They are intended to protect wildlife and human health. In addition, consumption advisories are issued when a guideline to protect human health is exceeded. Ontario publishes an annual guide which provides advise on the frequency of consumption, whether or not a guideline has been exceeded. The U.S. Great Lakes state agencies also issue advisories on an annual basis. The number of advisories on the Great Lakes has decreased over time, although it is difficult to generalise. Thirty-six of the 42 Areas of Concern have fish consumption advisories.

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1. INTRODUCTION

This part of the report discusses concentrations of toxic chemicals in aquatic biota, emphasising fish. It does not provide a comprehensive survey of the concentrations of all chemicals in all biota in all of the Great Lakes, or an exhaustive interpretation of chemical distributions and trends. Instead, it provides a broad perspective on the scope of the problem. The St. Lawrence River and the connecting channels have been included when data were available. Although the focus is the IJC's Critical Pollutants, other contaminants have been included when relevant and reliable data were available.

Many direct and indirect discharges of toxic chemicals have been reduced through improved industrial practices, more stringent regulations and restrictions or bans on the manufacture and use of some chemicals. As a result, contaminant burdens in some aquatic biota have decreased. However, even if the discharge of all chemicals were eliminated immediately, aquatic biota would continue to be exposed to toxic chemicals from three sources:

1. Contaminated Sediments

Contaminated sediments (also called in-place pollutants) will be a source of chemical contamination for many years. This problem is obviously more serious in heavily industrialized areas with a long history of discharges. Contaminants can be transferred from sediments to top predator fish species by biomagnification and bioaccumulation. These contaminants are returned to the sediments or lower trophic levels following the death and decomposition of upper trophic level organisms. As a result of the cyclic nature of these processes, sediment-related contaminant problems can affect fisheries long after direct discharges have been eliminated. Furthermore, fisheries can be contaminated by sediments in areas far removed from point sources of chemicals. For example, mirex from a single source in Lake Ontario has been spread to remote locations by the movement of contaminated sediments.

2. Long Range Atmospheric Transportation and Deposition of Toxic Chemicals

The long range transportation and deposition of toxic chemicals contributes significantly to the contamination of the Great Lakes basin. For example, atmospheric inputs represent more than 90% of the total loadings of PCBs to Lake Superior (see Table 2 in Part 1). Toxaphene is also known to be transported atmospherically. Most toxaphene use occurred outside the Great Lakes basin but it has been reported in lake trout from all of the Great Lakes. The relative importance of atmospheric deposition is dependent on the surface areas of the lakes and their turnover rates.

3. *Hazardous Waste Disposal Sites*

Hazardous waste disposal sites along the Niagara River have been implicated as sources of contaminants to Lake Ontario biota. Approximately 1.2 million tons of contaminated materials are stored in 66 sites and about 75% could be leached into the Niagara River and transported downstream to Lake Ontario. There are many other hazardous waste disposal sites in the Great Lakes basin that contain toxic chemicals which could leach into the lakes themselves and further contaminate the ecosystem.

The use of biotic components of the Great Lakes ecosystem to monitor contaminants is an integral component of the IJC's Great Lakes International Surveillance Plan (GLISP). Biomonitoring has the following advantages:

a) Biota are a link between sources of contaminants, ambient environmental levels and humans;
b) Biota concentrate and bioaccumulate contaminants. This allows the identification and quantification of toxic chemicals; and
c) Monitoring of levels of chemicals in biota or of biological parameters (such as growth rates and reproductive success) acts as an early warning system (IJC, 1981).

GLISP is a basin-wide internationally coordinated program designed to monitor trends in contaminant burdens in Great Lakes biota. Organic and inorganic contaminants are monitored annually in samples of young-of-the-year nearshore spottail shiners, open lake top predator and forage fish species (lake trout, walleye and smelt) as well as in herring gull eggs. Data from these surveys are analyzed to provide an assessment of temporal and spatial trends in the three trophic levels of the Great Lakes ecosystem. The state and provincial sport fish contaminant monitoring programs conducted in the basin are not intended to provide this type of information. However, data on fish of the same age can be used for trend analyses.

Aquatic biota other the fish have not been used extensively as biomonitors. However, organisms such as net plankton, *Mysis* and *Pontoporeia* have been used in several biomonitoring applications, including:

a) Evaluating the bioaccumulation of toxic chemicals from contaminated sediments in aquatic biota;
b) Quantifying spatial gradients of contaminants from point sources;
c) Identifying bioavailability and predicting the biomagnification of contaminants at increasing trophic levels by measuring contaminant burdens in fish and their diets, e.g., plankton, and benthic invertebrates; and
d) Providing an early warning mechanism to predict exposure of species at the higher trophic levels.

The uptake of organic contaminants by biota has been related to several factors experimentally. These include the chemical structure of the contaminant, its degree of hydrophobicity (i.e., its affinity for non-aqueous media, such as sediment and biota), lipophilicity (i.e., its affinity for lipid), and the magnitude and duration of exposure of the organism. Many studies have shown a direct relationship between lipid content and the contaminant burden of organisms. These factors are important in the interpretation of spatial and temporal data of contaminants in biota.

The usefulness of biomonitoring is enhanced when the data are normalized for lipid content and the age or size of the organism. A good example of this is a study undertaken to evaluate contaminant dynamics in the food web (Whittle, 1985b). It found that the highest levels of contaminants occurred in biota in the spring. But this finding was evident only after the data had been normalized on a lipid weight basis. In addition, lower tropic level organisms showed greater seasonal variations in contaminant concentrations. This indicates that lower trophic level organisms have shorter response times and are therefore more indicative of short-term changes in environmental concentrations.

Many factors influence fish burdens of organic and inorganic chemicals. These include the lipid content, age, position in the food web and the portion of the fish analyzed. To determine temporal and spatial trends it is necessary to standardize these factors. It is also necessary to ensure that there is adequate quality assurance and control. To assess temporal and spatial changes, the results of the national pesticide biomonitoring program, the Great Lakes environmental contaminant survey and the Great Lakes fish contaminant surveillance program have been used (Baumann and Whittle, 1988) because their methodologies are the best standardized.

2. CONCENTRATIONS OF CONTAMINANTS IN AQUATIC BIOTA

2.1 CONCENTRATIONS OF CONTAMINANTS IN INVERTEBRATES

There are only a few monitoring programs that provide information on spatial and temporal trends of contaminants in invertebrates. Contaminant burdens have been monitored in forage organisms, including surface plankton which comprise mostly microscopic forms (>153 µm) of plants (phytoplankton) and animals (zooplankton); the freshwater shrimp (*Mysis relicta*), a large zooplankton (which feeds in the water column); and the amphipod or scud (*Pontoporeia* sp.), a benthic invertebrate (which feeds on the sediments and sedimenting material). Contaminant monitoring data for invertebrates are available for Lakes Ontario (1977 to 1982), Erie (1980), Huron (1980 and 1983) and Superior (1983).

In 1983, the Ontario Ministry of the Environment (MOE) initiated its in-place pollutants program. As part of the program, benthic organisms, including the sludge worms (*Limnodrilus hoffmeisteri* and *Tubifex*), were analysed for heavy metals, PCBs and organochlorine pesticides. Data are available for 1983 from several nearshore and connecting channel locations, including the Toronto Waterfront, Hamilton Harbour, St. Marys River, St. Clair River, Niagara River and St. Lawrence River (Persaud *et al.*, 1987). The results demonstrate that oligochaetes have consistently bioaccumulated organic contaminants at some locations, particularly those in close proximity to riverine or point source (e.g., sewage treatment plant, storm sewer) discharges. Results from subsequent annual surveys have not been published.

The upper Great Lakes connecting channels study found that contaminant loadings to the St. Marys, St. Clair and Detroit Rivers have caused high levels of toxic chemicals in the water, sediments and biota. The study identified specific "zones of impairment" in each channel which were defined by an increased occurrence of pollution-tolerant benthic species and a decrease in the diversity of other benthic species (UGLCCS, 1989).

Other monitoring programs include the use of introduced (caged) or native clams to biomonitor the distribution, biological availability and source areas of contaminants. These have focused on the connecting channels, e.g., the Niagara River (Kauss *et al.*, 1981; Niagara River Toxics Committee, 1984) and the St. Clair - Detroit River system (e.g., Kauss and Hamdy, 1984; Pugsley *et al.*, 1985; 1988).

Contaminant burdens in surface net plankton, *Mysis* and *Pontoporeia* from the Great Lakes were monitored from 1977 to 1983.

2.1.1 Lake Ontario

Levels of organochlorines in Lake Ontario invertebrates are shown in Figure 1. This shows that there have been considerable variations in contaminant levels. Nevertheless, there has been a consistent decrease in concentrations of PCBs, p,p'-DDE and dieldrin in net plankton. This trend was not observed in *Mysis* and *Pontoporeia*. As expected, concentrations increased with trophic level.

Trace metal data showed no consistent trends. Concentrations of arsenic, cadmium, mercury and lead are shown in Figure 2.

It is possible to compare concentrations of organic contaminants in surface plankton in 1972, 1977 and 1982, and in *Pontoporeia* in 1972 and 1983 (Table 1). Contaminant concentrations in plankton in 1982 were approximately one to two orders of magnitude less than concentrations in the 1972 samples. For *Pontoporeia*, however, the data indicate that body burdens of total DDT, p,p'-DDE and dieldrin increased between 1972 and 1983, while PCB residues decreased by two orders of magnitude. Changes in residue levels for *Pontoporeia* for 1972 to 1983 may be a result of differences in analytical methods used. For plankton species composition of samples collected in 1972 was unlike that of the samples collected in 1977 and 1983. Because of these differences, no general conclusions can be drawn about temporal trends in concentrations of contaminants Lake Ontario invertebrates and plankton.

Spatial comparisons can also be made. Mean concentrations of heavy metals and mirex were higher in *Pontoporeia* samples collected from the western basin of Lake Ontario compared to similar samples from the eastern basin. Samples from the eastern basin had higher concentrations of p,p-DDE, total DDT and PCBs (Table 2).

TABLE 1. HISTORICAL CONCENTRATIONS OF ORGANIC CONTAMINANTS IN LAKE ONTARIO INVERTEBRATES (ppm, dry weight)

Parameter	Net Plankton			Pontoporeia	
	1972	1977	1982	1972[1]	1983
p,p'-DDE	3.11	0.04	0.03	0.12	0.24
Total DDT	3.46	0.12	< 0.01	0.21	0.64
Dieldrin	0.13	0.05	< 0.01	0.01	0.27
Total PCB	6.14	0.19	< 0.05	0.98	0.16

[1] *Pontoporeia* were collected from the western basin of Lake Ontario only.

Source: Haile *et al.*, 1975.

Data for later years are from the Department of Fisheries and Oceans

TABLE 2. MEAN CONCENTRATIONS OF CONTAMINANTS IN *PONTOPOREIA* FROM THE WESTERN AND EASTERN BASINS OF LAKE ONTARIO (ppm, dry weight)

Parameter	Western Basin	Eastern Basin
Arsenic	7.4	3.1
Copper	98.5	85.6
Lead	4.5	2.9
Mercury	0.40	0.09
Zinc	89.75	60
p,p'-DDE	0.292	0.730
Total DDT	0.440	1.088
Mirex	0.228	0.041
Total PCBs	1.378	1.849

Source: Whittle, D.M. and J.D. Fitzsimons, 1983.

2.1.2 Lake Erie

Net plankton were collected from Lake Erie in 1980 and net plankton and *Pontoporeia* were collected from the eastern basin of Lake Erie in 1981. Data on the contaminant burdens are shown and discussed in the section on inter-lake comparisons.

2.1.3 Lake Huron

Samples of plankton, *Mysis* and *Pontoporeia* were collected from up to five locations (Goderich, South Baymouth, Burnt Island-North Channel, Cape Rich, French River) in Lake Huron during 1980 and 1983. The 1983 data

TABLE 3. INTER-LAKE COMPARISON OF CONCENTRATIONS OF CONTAMINANTS IN NET PLANKTON (ppm, dry weight)

	Lake Ontario (1982)	Lake Erie (1980)	Lake Huron North Channel (1983)	Lake Superior (1983)	
Parameter				Whitefish Bay	Thunder Bay
Arsenic	3.8	-	2.4	2.0	3.8
Cadmium	1.4	-	1.3	2.7	1.6
Chromium	-	-	2.7	-	-
Copper	-	-	12.6	37.6	19.6
Lead	4.1	-	3.8	5.2	20.3
Mercury	0.05	-	0.83	0.07	0.10
Nickel	-	-	20.8	-	-
Selenium	1.8	2.1	1.8	2.5	1.0
Zinc	102.1	-	92.0	100.6	142.4
p,p'-DDE	0.03	-	< 0.01	-	-
Total DDT	< 0.01	-	< 0.01	0.02	< 0.01
Dieldrin	< 0.01	-	< 0.01	0.03	< 0.01
Mirex	< 0.01	-	< 0.01	< 0.01	< 0.01
Total PCBs	< 0.01	-	< 0.1	< 0.1	< 0.1

Source: Whittle, D.M., and J.D. Fitzsimons, 1983 (organochlorine data for fish from Lake Ontario). Other data from the Department of Fisheries and Oceans.

show that concentrations of cadmium, chromium, copper, lead, mercury, nickel and zinc in *Pontoporeia* samples collected from the North Channel site were significantly higher than those from the Goderich and South Baymouth sites. This may be because of differences in the geology of the two areas and the mining and smelting activities in Sudbury. Levels of organic chemicals were generally close to or below minimum detection levels. The PCB concentration (< 0.1 ppm) reported for net plankton in 1983 was considerably less than the levels (mean of 2.8 ppm, maximum of 8.1 ppm) reported by Glooschenko *et al.* (1976) for samples collected in 1974.

2.1.4 Lake Superior

Net plankton samples were collected in 1983 from Thunder Bay and Whitefish Bay. *Pontoporeia* were sampled from Whitefish Bay only. The PCB concentration (< 0.1 ppm) reported for net plankton in 1983 was considerably lower than the levels (mean of 0.6 ppm, maximum of 1.3 ppm) reported for seston in 1974 (Glooschenko *et al.*, 1976). The 1983 data on contaminant

TABLE 4. INTER-LAKE COMPARISON OF CONCENTRATIONS OF CONTAMINANTS IN *MYSIS* (ppm, dry weight)

Parameter	Lake Ontario (1980, 1982)[1]	Lake Huron (1983)	Lake Superior Whitefish Bay (1983)
Arsenic	4.0	3.0	3.0
Cadmium	0.12	0.17	0.15
Chromium	-	3.4	-
Copper	-	20.3	15.1
Lead	2.9[2]	< 1.0	< 0.5
Mercury	0.03	0.10	0.10
Nickel	-	1.5-17.5[3]	-
Selenium	2.5	3.2	2.9
Zinc	80.5	74.7	70.4
p,p'-DDE	0.14	0.03	-
Total DDT	0.20	0.03	0.02
Dieldrin	0.07	0.01	0.02
Mirex	< 0.01	< 0.01	< 0.01
Total PCBs	0.58	< 0.1	< 0.1

Source: Department of Fisheries and Oceans

[1] 1980 data for heavy metals; 1982 data for organics

[2] collected in 1979

[3] range

burdens are shown and discussed in the next section on inter-lake comparisons.

2.1.5 Discussion

The most recent data on contaminant burdens in net plankton, *Mysis* and *Pontoporeia* from Lakes Ontario, Erie, Huron and Superior are shown in Tables 3, 4 and 5, respectively. In general, cadmium, lead, mercury and selenium levels were slightly higher in subvertebrate fauna from Lakes Huron and Superior than from Lake Ontario. This may reflect the different geologies of the lake basins. Arsenic levels were generally higher in subvertebrate biota from Lake Ontario. Furthermore, levels of PCBs and organochlorine pesticide were higher in subvertebrate biota from Lake Ontario. This is probably because of the extensive industrial and agricultural activities in the Lake Ontario basin.

Table 6 contains a summary of the contaminant concentrations in invertebrates for each lake and connecting channel. Most of these data are not amenable to temporal or spatial trend analysis because different sampling locations were used, different types of organisms were sampled, there was sampling discontinuity over time and there was no inter-laboratory quality assurance.

TABLE 5. INTER-LAKE COMPARISON OF CONCENTRATIONS OF CONTAMINANTS IN *PONTOPOREIA* (ppm, dry weight)

Parameter	Lake Ontario (1982, 1983)[1]	Lake Erie (1981)	Lake Huron (1983)	Lake Superior Whitefish Bay (1983)
Arsenic	5.6	-	5.8	6.0
Cadmium	1.5	-	1.6	4.9
Chromium	-	-	2.9-13.2[3]	-
Copper	-	-	139.5	20.8
Lead	1.7	-	2.2	2.4
Mercury	0.08	-	0.06-0.22	0.12
Nickel	-	-	3.0-21.2	-
Selenium	1.1	-	2.7	3.2
Zinc	48.0	-	69.5	77.8
p,p'-DDE	0.25	0.06	< 0.01	-
Total DDT	0.66	0.11	< 0.01	-
Dieldrin	0.28	0.06	< 0.01	-
Mirex	0.12[2]	< 0.01	< 0.01	-
Total PCBs	1.35	0.56	< 0.1	-
Chlordane	-	0.03	-	-

Source: Department of Fisheries and Oceans

1. 1982 data for inorganics; 1983 data for organics
2. 1980 data
3. range

TABLE 6: SUMMARY OF CONTAMINANTS DETECTED IN GREAT LAKES INVERTEBRATES

Parameter	Organism Type[1]	St. Lawrence River	Lake Ontario	Niagara River	Lake Erie	St. Clair-Detroit River	Lake Huron	Lake Michigan	St. Marys River	Lake Superior	References[2]
Metals											
Antimony	B, P, Z							X			29
Arsenic	NP, M, A		X				X			X	1, 2, 3
	O		X	X					X		8
	A									X	11
	C			X							20
	B, P, Z							X			29
Barium	B, P, Z							X			29
Cadmium	NP, M, A		X				X			X	1, 2, 3
	O		X	X		X			X		8
	C			X		X					17, 20
Chromium	NP, M, A						X				1
	A									X	11
	B, P, Z							X			29
Cobalt	B, P, Z							X			29
Copper	NP, M, A						X			X	1, 2
	O		X	X		X			X		8
	A									X	11
	C			X							20
	B, P, Z							X			29
Iron	O		X	X		X			X		8
	A									X	11
	C			X							20
	B, P, Z							X			29
Lead	NP, M, A		X				X			X	1, 2, 3
	O		X	X		X			X		8
	C	X				X					16, 17
Manganese	O		X	X		X			X		8
	B, P, Z							X			29
Mercury	NP, M, A		X				X			X	1, 2, 3
	O		X	X					X		8
	A									X	11
	C			X							20
	CM				X						22, 23
	B, P, Z							X			29
Molybdenum	B, P, Z							X			29
Nickel	NP, M, A						X				1
Selenium	NP, M, A		X				X			X	1, 2, 3
	NP				X						5, 24
	C			X							20
	B, P, Z							X			29

TABLE 6: CONTINUED

Parameter	Organism Type¹	St. Lawrence River	Lake Ontario	Niagara River	Lake Erie	St. Clair-Detroit Rivers	Lake Huron	Lake Michigan	St. Marys River	Lake Superior	Reference²
Silver	B, P, Z							X			29
Strontium	B, P, Z							X			29
Vanadium	B, P, Z							X			29
Zinc	NP, M, A		X				X			X	1, 2, 3
	O		X	X		X			X		8
	A									X	11
	C			X							20
	B, P, Z							X			29
Alkyllead	C	X									16
Organic Contaminants											
Aldrin	O		X								8
	C					X					19
Dieldrin	NP, M									X	2
	NP, M, A		X								3
	NP, A		X								4, 25
	A				X						7
	C			X							20
	NP						X			X	21
	M							X			30
p,p-DDE	NP, M, A		X								3
	NP, A		X								4, 25
	A				X						7
	O		X			X					8, 9
	C					X					19
	NP						X			X	21
	M							X			30
p,p-DDD	NP, A		X								4, 25
	O		X			X					8, 9
	C					X					19
	M							X			30
p,p-DDT	NP, A		X								4
	O					X					9
	C			X		X					14, 19
	A		X								25
	M							X			30
Total DDT	NP, M, A		X							X	2, 3
	NP, A		X								4
	O		X								6
	A				X						7
	C			X							20
	NP									X	27
	M							X			30
Mirex	A		X								3, 25

TABLE 6: CONTINUED

Parameter	Organism Type¹	St. Lawrence River	Lake Ontario	Niagara River	Lake Erie	St. Clair-Detroit Rivers	Lake Huron	Lake Michigan	St. Marys River	Lake Superior	Reference²
Endrin	C			X							20
	NP		X								25
Alpha-BHC	O		X			X					8, 9
	C			X							14,19, 20
	A		X								25
Beta-BHC	C			X							14
	A		X								25
Chlordane	O		X			X					6, 8, 9
	A				X						7
	C			X		X					14, 19, 20
	NP, A		X								25
	M							X			30
PCB	NP, A		X								4, 25
	O		X			X		X			6,8,9,10
	A				X			X			7, 28
	O, A, M		X								12
	C			X		X					13,14,19,20
	NP									X	21, 27
	M							X			30
Lindane	O		X								6, 8
	C			X							14
	A		X								25
Hexachlorobenzene	O			X			X				6, 8, 9
	O, A, M		X								12
	C			X		X					14,19,20
	NP, A		X								25
	M							X			30
Heptachlor	O		X								8
Heptachlor epoxide	C			X							14, 20
	NP		X								25
Nonachlor	O					X					9
Chlorobenzenes	O, A, M		X			X					12, 19
Octachlorostyrene	C					X					13, 19
Hexachlorobutadiene	O, A, M			X							12
	C					X					19
Chlorotoluenes	C					X					19
Phenanthrene	A						X				15
	O, CM				X						18
Anthracene	A							X			15
	O, CM				X						18

TABLE 6: CONTINUED

Parameter	Organism Type[1]	St. Lawrence River	Lake Ontario	Niagara River	Lake Erie	St. Clair-Detroit Rivers	Lake Huron	Lake Michigan	St. Marys River	Lake Superior	Reference[2]
Fluoranthene	A							X			15
	O, CM				X						18
Pyrene	A							X			15
	O, CM				X						18
Chrysene	A							X			15
	O, CM				X						18
Benzo(a)pyrene	A							X			15
	O, CM				X						18
Benzo(g)pyrene	O, CM				X						18
Palmitic acid	NP									X	26
Dehydroabietic acid	NP									X	26
Dioctyl phthalate	NP									X	26

1 NP = net plankton; M = mysids; A = amphipods; O = oligochaetes; C = clams; CM = chironomids (midges), B = benthos; P = phytoplankton; Z = zooplankton.

2 References: 1. Whittle (1987); 2. Whittle (1985c); 3. Whittle (1985b); 4. Haile *et al.* (1975); 5. Hodson *et al.* (1984a); 6. Harlow and Hodson (1988); 7. Whittle and Fitzsimons (1983); 8. Persaud *et al.* (1987); 9. Smith *et al.* (1985); 10. Darkin *et al.* (1988); 11. Heimke *et al.* (1976); 12. Fox *et al.* (1983); 13. Pugley *et al.* (1985); 14. Niagara River Toxics Committee (1984); 15. Eadie *et al.* (1982a); 16. Wong *et al.* (1988); 17. Pugsley *et al.* (1988); 18. Eadie *et al.* (1982b); 19. Kauss and Hamdy (1985); 20. Kauss *et al.* (1981); 21. Glooschenko *et al.* (1976); 22. Walters *et al.* (1972); 23. Skoch and Sikes (1973); 24. Adams and Johnson (1977); 25. Suns *et al.* (1978); 26. Brownlee and Strachan (1977); 27. Veith *et al.* (1977); 28. Veith (1973); 29. Copeland and Ayers (1972); 30. Evans *et al.* (1982).

2.2 CONCENTRATIONS OF CONTAMINANTS IN FISH

Fish are excellent indicators of ecosystem health because they are exposed to aquatic contaminants and they bioaccumulate many of them. Many toxic chemicals cannot be detected in water because they are present at concentrations below the minimum detection levels of standard analytical procedures. Concentrations in fish can be used to assess water quality if the bioaccumulation and biomagnification factors are known.

There are three programs that examine concentrations of toxic chemicals in fish: the open-lake fish contaminants program, the nearshore juvenile fish contaminants surveillance program and the sport fish testing program.

The open-lake fish contaminants program (conducted by the Department of Fisheries and Oceans in Canada and the U.S. Fish and Wildlife Service/ Environmental Protection Agency) measures the concentrations of several organic contaminants and some metals annually in two types of fish:

a) Forage fish, represented by rainbow smelt (*Osmerus mordax*) and bloater chub (*Coregonus hoyi*) from Lake Michigan. These species feed mainly on plankton; and

b) Top predator fish, represented by lake trout between four and five years old (*Salvelinus namaycush*) and walleye (*Stizostedion vitreum*) from Lake Erie. These species feed mainly on other fish.

Lake trout are useful indicators of ecosystem contamination because they are high on the food web, have a high lipid content, great mobility and a long life span. Other fish species, e.g., splake (lake trout x brook trout hybrid), sculpin (*Cottus* sp.), coho salmon (*Oncorhynchus kisutch*) and carp (*Cyprinus carpio*), have been used in programs to investigate specific problems. The Open Lake Program has used whole fish homogenates to determine contaminant levels because fish accumulate contaminants in non-edible tissues. The U.S. program has used fish size (total length) as the dependent variable for measuring changes in contaminant levels over time (DeVault *et al.*, 1986; Hesselberg *et al.*, 1988). In contrast, the Canadian program has used age. Since age and size measurements have been well-correlated for each lake, either can be used. The open-lake collection sites for fish are shown in Figure 3.

In 1975, the Ontario Ministry of the Environment (MOE) initiated its nearshore juvenile fish contaminants surveillance program. This involved the collection and analysis of spottail shiners (*Notropis hudsonius*) from nearshore and connecting channel locations, especially the Areas of Concern. The New York State Department of Environmental Conservation (NYDEC) has recently started a similar program. Spottail shiners are plentiful throughout the Great Lakes basin, making inter-lake and intra-lake comparisons feasible. The analysis of only young-of-the-year fish obviates the need for age/size normalization. The spottail shiner has a limited range, so body burdens can be related to local conditions. They can also be used to track the effectiveness of remedial actions. Spottail shiner collection sites are identified in the discussion on each lake (Figures 5, 24, 33, 40, 50, 53, and 54).

The open-lake and nearshore programs have continuous historical data sets from 1977 and 1975, respectively. Both programs measure whole fish levels. They can be used to assess temporal and spatial trends.

The Ontario Ministry of the Environment's sport fish testing program was established to analyze fish samples for various toxic contaminants and to provide data to guide the development of fish consumption advisories (Ontario Government, 1977). The program includes the publication of the "Guide to Eating Ontario Sport Fish". The guide lists fish consumption advisories by waterbody, fish species and length class and covers a range of contaminants, including ten metals, five pesticides, PCBs, hexachlorobenzene (HCB), mirex and 2,3,7,8-TCDD (dioxin). It is revised annually. The 1990 edition (MOE/MNR, 1990) provides advice on the consumption of fish from 1700 locations in Ontario including the following locations in the Great Lakes: St. Lawrence River (13 locations), Lake Ontario (37 locations), Niagara River (4 locations) Lake Erie (16 locations), Detroit River (3 locations), Lake St. Clair (1 location), St. Clair River (5 locations), Lake Huron (20 locations), Georgian Bay (37 locations), North Channel (11 locations), St. Marys River (1 location) and Lake Superior (49 locations). In contrast to the open-lake and spottail shiner programs discussed above, samples of lean, skinless dorsal muscle tissue are analysed. The consumption advisories are based on this portion of the fish. The eight Great Lakes states have also implemented sport fish testing programs to provide guidance on fish consumption, but some of these analyse 'skin-on' samples so the results are not directly comparable to those from the Ontario Ministry of the Environment's program. This program cannot be used to assess spatial or temporal trends because fish from a particular region are sampled only once every three years and the collection sites are not fixed.

There are some other data on levels of toxic chemicals in fish. Most of this information is from short-term studies designed to determine if, and in what amounts, contaminants are present in Great Lakes fish. These 'snapshots' are not generally amenable to temporal and spatial analyses, but have provided the basis for some consumption advisories. A few of these programs can provide limited information on trends, and the relevant data have been included in the following sections.

Relevant data for specific IJC Critical Pollutants are shown by lake or connecting channel. In general, data points are sample means (the data for each sample divided by the total number of samples). Standard errors and standard deviations have been included, when available. Levels of each chemical can be compared to the specific objectives in the Great Lakes Water Quality Agreement.

It should be noted that only information generated by individual laboratories with demonstrable internal quality control programs has been used in this report for trend descriptions. An effective inter-laboratory quality assurance program must be in place before multiple source data sets can be utilized to generate temporal or spatial trend information. In addition all samples analyzed must have been collected and prepared in a similar manner to permit comparison of the resulting analytical data. The IJC Data Quality Workgroup conducts inter-laboratory round robins to compare data generated on a common set of parameters by laboratories generating data for Great Lakes Studies.

2.2.1 Lake Ontario

Total PCBs

Temporal Trends:

In 1977, the use of PCBs was restricted under the Environmental Contaminants Act. Since then, total PCB burdens have decreased in fish from Lake Ontario (Figure 4). Specifically, concentrations of total PCBs in lake trout decreased from 1978 to 1981 and from 1983 to 1984. However, increases occurred in 1981 and 1982. There are several possible explanations for this including the closure of a major sewage treatment plant during this time. Temporal trends in rainbow smelt were similar to those in lake trout. In 1985 and 1986, concentrations of PCBs were the lowest reported since monitoring began. Despite the reduction in levels, PCB concentrations in the two species are above the GLWQA specific objective of 0.1 ppm for whole fish.

A map of the Lake Ontario basin tributaries where spottail shiners are collected is shown in Figure 5. PCB burdens in spottail shiners from Lake Ontario were statistically ($p< 0.01$) lower in 1982-1983 than in the mid-1970s (Suns *et al.*, 1985). The rate of decline in residue levels had decreased considerably by the mid 1970s. During the early 1980s (1979-1983) the concentration averaged 28 ppb, as compared to 84 ppb over the entire study period (1975-1983). Figure 6 shows the decrease in total PCB burdens in spottail shiners collected from four locations on Lake Ontario. Concentrations have levelled off in the Twelve Mile Creek, the Humber River and the Credit River populations, however, levels in all samples are above the GLWQA specific objective of 0.1 ppm. Concentrations in the Humber River sample levelled off at the highest concentration of approximately 0.5 ppm.

A similar pattern is evident in coho salmon from the Credit River that were collected as part of the Ontario Ministry of the Environment's sport fish testing program (Figure 7), although these data are for total PCBs in lean dorsal muscle tissue. All of the available data suggest that total PCB concentrations in fish have decreased significantly since the 1970s, but equilibrated in the 1980s. This may reflect the cycling of PCBs through the environment and the importance of non-point sources, such as sediments and the atmosphere.

Spatial Distribution:

The spatial distribution of PCB burdens in Lake Ontario spottail shiners is shown in Table 7. High concentrations were found in populations at Mimico Creek in 1983 (0.54 ppm) and the Humber River in 1983 (0.54 ppm). The Ganaraska River population had the highest overall concentration for Lake Ontario (1.20 ppm).

TABLE 7. MEAN CONCENTRATIONS OF PCBS IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE ONTARIO (ppm, wet weight)

Location	Year	Mean PCB Concentration
Niagara on the Lake	1983	0.14
Outlet River	1982	0.13
Wolfe Island	1983	0.08
Cataraqui River	1980	0.10
Oswego River	1984	0.09
Salmon River	1984	0.10
Black River Bay	1984	0.31
Welland Canal	1983	0.23
Twelve Mile Creek	1983	0.24
Burlington Beach	1983	0.38
Bronte Creek	1979	0.19
Credit River	1983	0.33
Mimico Creek	1983	0.54
Humber River	1983	0.54
Toronto Harbour	1979	0.42
Rouge River	1979	0.08
Oshawa Creek	1982	0.23
Ganaraska River	1980	1.20

Source: K. Suns, in press.

Suns *et al.* (1985) determined mean PCB residue levels in spottail shiners from western and eastern Lake Ontario. PCB residue levels in 1982/3 were 0.354 ppm in the western basin and in the eastern basin they were more than double this. Inter-basin differences in PCB concentrations have also been reported by Whittle and Fitzsimons (1983) who found that mean concentrations in lake trout and slimy sculpin were significantly ($p < 0.05$) greater in the western basin than in the eastern basin. These data suggest that the Niagara River is a major source of PCBs to Lake Ontario.

Mirex

Temporal Trends:

Mirex levels have decreased in fish from Lake Ontario as a result of legislation enacted in the mid-1970s to ban the production and use of mirex. Concentrations of mirex in rainbow smelt from Lake Ontario have decreased, with the lowest concentration (0.01 ppm) occurring in 1984-1986 (see Figure 8). Mirex burdens in lake trout decreased significantly in 1980 and 1984. The concentration in 1986 lake trout (0.06 ppm) was the lowest recorded during the survey. Concentrations in both species exceed the GLWQA specific objective of "substantially absent".

Mirex levels in spottail shiners (Figure 9) also decreased significantly in the late 1970s. Concentrations increased in the Niagara-on-the-Lake population in 1980 and at Twelve Mile Creek in 1981. Levels continue to fluctuate but may have reached an equilibrium dependent on sediment remobilization. Historical point sources on the Niagara River and at Oswego N.Y. are no longer significant.

Spatial Distribution:

Table 8 shows mirex concentrations in spottail shiners from Lake Ontario. Detectable concentrations were found in fish from ten locations on both sides of the lake. The highest levels were at Oshawa Creek and Twelve Mile Creek. Trace concentrations were found in populations sampled at the Welland Canal in 1983 and Toronto Harbour in 1979. Mirex was not detected at six other locations.

TABLE 8. MEAN CONCENTRATIONS OF MIREX IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE ONTARIO (ppm, wet weight)

Location	Year	Mean Mirex Concentration
Niagara-on-the-Lake	1983	ND
Welland Canal	1983	TR
Twelve Mile Creek	1983	0.008
Burlington Beach	1983	0.007
Bronte Creek	1979	ND
Credit River	1983	0.005
Mimico Creek	1983	ND
Humber River	1983	ND
Toronto Harbour	1979	TR
Rouge River	1979	ND
Oshawa Creek	1982	0.009
Ganaraska Creek	1980	0.006
Outlet River	1982	0.007
Wolfe Island	1983	0.007
Cataraqui River	1980	ND
Oswego River	1984	0.004
Salmon River	1984	0.004
Black River Bay	1984	0.004

ND = not detected
TR = trace detected
Minimum detection level = 5 ppb

Source: K. Suns, in press.

Whittle and Fitzsimons (1983) reported that mean concentrations of mirex in rainbow smelt and slimy sculpin were significantly ($p < 0.05$) higher in fish from the western basin of Lake Ontario, compared to the eastern basin. This further supports the hypothesis that the Niagara River is the main source of the mirex to Lake Ontario.

In addition to the lake-wide contamination of aquatic biota, upstream dispersal may be occurring in previously uncontaminated tributaries. Anadromous migration, spawning and subsequent carcass decomposition of salmonids may result in the incorporation of mirex into stream food webs and terrestrial biota (Low, 1983).

Hexachlorobenzene (HCB)

Temporal Trends:

There are insufficient data to evaluate temporal trends in HCB levels in fish from Lake Ontario definitively. Data presented by Harlow and Hodson (1988) suggest that HCB levels in sport fish from Hamilton Harbour decreased significantly between 1972 and 1981 (Table 9). However, these data must be interpreted cautiously because of problems with inter-laboratory quality assurance.

Data on HCB concentrations in spottail shiners collected by the Ontario Ministry of the Environment over several years also suggest that levels have decreased. For example, HCB burdens in spottail shiners from Niagara-on-the-Lake decreased consistently from 0.012 ppm in 1979 to 0.003 ppm in 1983 (Figure 10).

TABLE 9. TEMPORAL TRENDS IN CONCENTRATIONS OF HCB IN SPORT FISH FROM HAMILTON HARBOUR (ppm, wet weight)

Year	brown bullhead	white perch	carp	coho salmon
1972	0.028	0.096	-	-
1978	0.002	0.002	0.006	0.008
1979	-	-	-	< 0.001
1981	<0.0001	0.0011	< 0.0001	-

Source: Harlow, H.E. and P.V. Hodson, 1988

Spatial Distribution:

The Ontario Ministry of the Environment's nearshore juvenile fish contaminant surveillance program database provides the most extensive information on the spatial distribution of HCB in Lake Ontario fish (Table 10). HCB was detected in more than 50% of the Lake Ontario population studied in 1982-84. The highest concentrations were found in spottail shiner populations at Mimico Creek and the Humber River (1983 data).

Dieldrin

Dieldrin burdens in lake trout from Lake Ontario peaked in the late 1970s. Since then, levels have decreased (Figure 11). It is difficult to explain

TABLE 10. MEAN CONCENTRATIONS OF HCB IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE ONTARIO (ppm, wet weight)

Location	Year	Mean HCB Concentration
Niagara-on-the-Lake	1983	0.003
Welland Canal	1983	0.003
Twelve Mile Creek	1983	0.005
Burlington Beach	1983	0.002
Credit River	1983	0.002
Mimico Creek	1983	0.013
Humber River	1983	0.013
Oshawa Creek	1982	0.002
Outlet River	1982	TR
Wolfe Island	1983	TR
Oswego River	1984	ND
Salmon River	1984	ND
Black River Bay	1984	ND

ND = not detected
TR = trace detected
Minimum detection level = 1 ppb

Source: K. Suns, in press.

the apparent increase in dieldrin levels in lake trout between 1982 and 1984. Levels in 1986 and 1987 suggest that the concentrations have equilibrated. More data will be required to determine if this equilibrium persists. Dieldrin levels in rainbow smelt from Lake Ontario have varied from year to year and show no obvious trends.

DDT and Metabolites

Temporal Trends:

Levels of both total DDT and its main metabolite p,p'-DDE, have been determined in fish. p,p'-DDE is the most prevalent DDT metabolite in the Great Lakes ecosystem and it is more readily taken up by aquatic organisms than the parent compound.

Total DDT concentrations in forage and top predator fish have decreased although there have been considerable yearly variations (Figure 12). These data reflect the restrictions on the use of DDT imposed by the U.S. and Canada in the early 1970s. Since 1985, total DDT burdens in lake trout

TABLE 11. CONCENTRATIONS OF TOTAL DDT IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE ONTARIO (ppm, wet weight)

Location	Year	Mean Total DDT Concentration
Niagara-on-the-Lake	1983	TR
Welland Canal	1983	0.038
Twelve Mile Creek	1983	0.048
Burlington Beach	1983	0.040
Bronte Creek	1979	0.035
Credit River	1983	0.023
Mimico Creek	1983	0.041
Humber River	1983	0.048
Toronto Harbour	1979	0.082
Rouge River	1979	0.026
Oshawa Creek	1982	0.027
Ganaraska River	1980	0.170
Outlet River	1982	0.007
Wolfe Island	1983	0.016
Cataraqui River	1980	0.017

TR = trace detected

Source: K.Suns, In press.

have equilibrated near the GLWQA specific objective of 1.0 ppm in whole fish.

p,p'-DDE burdens in rainbow smelt and lake trout are shown in Figure 13. They are similar to the temporal trends in total DDT. As expected p,p'-DDE concentrations are lower than total DDT levels.

DDT levels also decreased in young-of-the-year spottail shiners at the Niagara-on-the-Lake and the Humber River collection sites (Figure 14). In contrast, DDT burdens in the Twelve Mile Creek population have continued to fluctuate widely since the early 1970s with the highest concentrations occurring in 1986. Burdens were considerably below the GLWQA specific objective of 1.0 ppm at all three locations.

The available data suggest that, while total DDT and p,p'-DDE concentrations in fish are lower than in the 1970s, levels have equilibrated since then. This equilibrium is probably dependent on inputs from contaminated sediments and atmospheric deposition (wet and dry). Atmospheric deposition of total DDT to Lake Ontario has been estimated at 0.14 tonnes/year (Eisenreich *et al.*, 1981).

Spatial Distribution:

Total DDT has been detected in spottail shiners from all collection sites in Lake Ontario in all years that samples were collected (Table 11). Concentrations were below the GLWQA specific objective of 1.0 ppm. The highest DDT concentrations were found in 1980 in spottail shiners from the Ganaraska River (0.170 ppm).

Whittle and Fitzsimons (1983) reported that mean total DDT concentrations in lake trout and slimy sculpin were significantly ($p < 0.05$) higher in the western basin than in the eastern basin of Lake Ontario. This suggests that the Niagara River may be an important source of DDT to Lake Ontario.

Dioxins and Furans

Temporal Trends:

Temporal data are available for 2,3,7,8-TCDD concentrations in lake trout from Lake Ontario although they have not been normalized for age (the mean age varied from 2.5 to 5.6 years) or length. Concentrations of 2,3,7,8-T-CDD have fluctuated and there is little indication of any significant changes from 1979 to 1987 (Figure 15). Love Canal is probably a major source of this congener to Lake Ontario (Suns *et al.*, 1985).

Spatial Distribution:

Fish from several locations in the Great Lakes have been analysed for PCDDs and PCDFs. The species sampled included offshore species, such as lake trout and bloater, and nearshore species, such as common carp (Petty *et al.*, 1983; Devault, 1984).

In 1984, lake trout and walleye from each of the Great Lakes and Lake St. Clair were analyzed for PCDD and PCDF congeners (DeVault et al, 1989). Total PCDD concentrations were highest in fish from Lake Ontario (65 ppt) and lowest in fish from Lake Superior (7 ppt), based on composites of five whole fish. The highest levels of 2,3,7,8-TCDD were found in lake trout from Lake Ontario (49 ppt). Total PCDF concentrations were the highest in fish from Lake Michigan (102 ppt) and the lowest in fish from Lake Superior (21 ppt).

TABLE 12. MEAN CONCENTRATIONS OF TOXAPHENE IN LAKE TROUT FROM LAKE ONTARIO, 1977-1986 (ppm, wet weight)

Year	Age of Fish (Years)	Mean Toxaphene Concentration
1977	5	3.5
1978	3	11.5
1980	5	0.2
1982	10	3.6
	6	3.0
	5	1.4
	4	0.6
1985/86	4	0.6

Source: Department of Fisheries and Oceans

The composition of PCDD and PCDF mixtures and the concentrations of the individual congeners vary considerably from lake to lake. This reflects differences in the amounts and types of PCDD and PCDF loadings. While atmospheric deposition is significant, there are also important local sources (DeVault *et al.*, 1989). Figures 16 and 17 show the concentrations of PCDDs and PCDFs in lake trout and walleye collected in 1984.

Toxaphene

Temporal trends of toxaphene in lake trout from Lake Ontario can not be assessed, since the data are very limited (Table 12). They suggest that there may be a decrease in toxaphene levels in fish from Lake Ontario, however, the results were not normalized for age.

Chlordane

Concentrations of chlordane in spottail shiners from Niagara-on-the-Lake and the Humber River are shown in Figure 18. In 1978, there were fluctuations in both populations. Since then, levels have decreased.

Other Pesticides

Suns *et al.* (1985) reported that levels of aldrin, endrin, thiodan, heptachlor, heptachlor epoxide and total hexachlorocyclohexane (BHC) were low in all samples of spottail shiners.

Polynuclear aromatic hydrocarbons (PAHs)

There are limited data available on PAH residues in fish. Concentrations of specific PAHs in fish from Hamilton Harbour are shown in Table 13. Concentrations are consistently higher in carp than in pike.

TABLE 13. PAH CONCENTRATIONS IN FILLETS OF FISH FROM HAMILTON HARBOUR (ppt, wet weight)

	Mean PAH Concentration			
Species	**Perylene**	**Benzo(k) fluoranthene**	**Benzo(a) pyrene**	**Coronene**
Carp	25.5	8.2	50.7	183.0
Pike	18.5	7.4	28.8	65.8

Source: Harlow, H.E. and P.V. Hodson, 1988

Total Lead

Lead in the environment can occur as inorganic lead or as organic (alkyl) lead. Traditionally, lead contamination has been assessed by measuring inorganic lead. However, recently, techniques have been developed to measure organic lead. Alkyl lead is more toxic than inorganic lead and its bioaccumulation factor is an order of magnitude greater than that for inorganic lead.

Spatial Distribution:

The highest concentration of total lead (0.40 ppm) was found in yellow perch from Toronto Harbour (Table 14). In general, concentrations were higher in forage fish from Cobourg, Port Credit, Point Traverse and the eastern basin of Lake Ontario than in top predator species from the same sites. This is because forage fish feed mainly on invertebrates which have relatively high concentrations of lead. Top predators consume a smaller proportion of invertebrates and a larger proportion of less contaminated fish.

Mercury

Bacteria in the aquatic ecosystem convert inorganic mercury into methylmercury (the organic form). Methylmercury in water is rapidly absorbed through the gills. It can also be ingested with food. Mercury is bioaccumulated and it is eliminated slowly.

TABLE 14. MEAN CONCENTRATIONS OF TOTAL LEAD IN FISH FROM LAKE ONTARIO (ppm, wet weight, whole fish)

Location	Species	Mean Total Lead
Eastern Basin	Lake trout	< 0.1
	Yellow perch	0.19
	Rainbow smelt	0.12
Point Traverse	Lake trout	< 0.1
	Rainbow smelt	0.12
Cobourg	Lake trout	< 0.1
	Rainbow smelt	0.22
Toronto	Yellow perch	0.40
Port Credit	Lake trout	< 0.1
	Coho salmon	0.12
	Rainbow smelt	0.16
Niagara	Coho salmon	0.13
	Rainbow smelt	0.09

Source: P. Hodson *et al.*, 1984b

Temporal Trends:

Mercury burdens in rainbow trout and lake trout from Lake Ontario have fluctuated (Figure 19). This may be because of variations in background levels from natural sources. However, there has been a decrease in mercury burdens in lake trout and levels are now below the Great Lakes Water Quality Agreement objective of 0.5 ppm. Mercury residues in spottail shiners from Niagara-on-the-Lake, the Humber River and the Credit River have also fluctuated.

Spatial Distribution:

Levels of mercury in young-of-the-year spottail shiners collected from Niagara-on-the-Lake (0.043 ppm) and the Welland Canal (0.054 ppm) in 1982 were higher, relative to levels in spottail shiners from other Lake Ontario collection sites. The concentrations in all fish sampled were below the GLWQA specific objective.

Other Contaminants

Some of the data on concentrations of arsenic, selenium and zinc in fish from Lake Ontario are shown in Figures 20, 21 and 22. There are no obvious trends in the concentrations of these metals in lake trout.

2.2.2 Lake Erie

Total PCBs

Temporal Trends:

In 1980, total PCB burdens in walleye from Lake Erie decreased significantly. Since then, levels have fluctuated (Figure 23). In 1987, the mean PCB concentration was 1.3 ppm. This is considerably above the GLWQA specific objective of 0.1 ppm in whole fish. Concentrations of PCBs in rainbow smelt fluctuated over the study period (1977-1987).

A map showing spottail shiner collection sites is shown in Figure 24. PCB burdens in spottail shiners from Leamington also decreased sharply in 1980 and have equilibrated since then (Figure 25). PCB burdens in spottail shiners from Big Creek showed no temporal trends. Suns *et al.* (1985) reported that PCB levels in spottail shiners from Lake Erie were significantly lower ($p < 0.01$) in 1982-1983 than in the mid 1970s. PCB burdens in spottail shiners from these two locations were above the GLWQA specific objective in 1985.

Spatial Distribution:

The highest PCB burden in spottail shiners was found at the Leamington site (0.26 ppm in 1983). Fish from four of ten Lake Erie locations had concentrations in excess of the GLWQA specific objective. Concentrations varied throughout the lake and ranged between 0.03 and 0.26 ppm (Table 15). This may indicate the presence of local point sources because spottail shiners have a small geographic range.

Suns *et al.* (1985) found that mean PCB residues in spottail shiners were greater in the western basin than in the eastern basin of Lake Erie. Mean concentration in the west were 0.227 ppm and 0.040 ppm in the east for samples collected in 1982-1983.

TABLE 15. MEAN CONCENTRATIONS OF PCBS IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM CANADIAN AND U.S. SITES ON LAKE ERIE (ppm, wet weight)

Location	**Year**	**Mean PCB Concentration**
Big Creek	1982	0.19
Leamington	1983	0.26
Port Rowan	1979	0.03
Port Stanley	1983	0.23
Centre Creek	1983	0.05
Nanticoke Creek	1982	0.03
Grand River	1982	0.05
Thunder Bay	1983	0.03
Dunkirk Harbour (NY)	1984	0.04
Smokes Creek (NY)	1984	0.10

Source: K. Suns, Ontario Ministry of the Environment.

Mirex

Mirex was not detected (< 5 ppb) in the young-of-the-year spottail shiners collected from Lake Erie. This is consistent with the observation that point sources of mirex to the Great Lakes were located in the Lake Ontario basin.

Hexachlorobenzene (HCB)

The analysis of spottail shiners by the MOE provides information on HCB burdens in Lake Erie fish from sites in Canada and the U.S. HCB was detected in two of the nine samples collected between 1982 and 1984. Detectable levels (> 1 ppb) were found in spottail shiners from Big Creek and Leamington. HCB was detected in other fish species from the Ashtubula River. This river is an Area of Concern because of contaminated sediments.

Dieldrin

Figure 26 shows levels of dieldrin in walleye from Lake Erie from 1978 to 1986. Levels in this top predator have varied significantly from year to year and there are no obvious temporal trends. Since 1979, concentrations in whole fish have been below the minimum detection limit of 0.1 ppm. Contaminant levels of dieldrin in rainbow smelt have been consistently below the minimum detection limit.

DDT and Metabolites

Temporal Trends:

Total DDT and p,p'-DDE levels also decreased sharply in the late 1970s and then equilibrated (Figures 27 and 28). Levels have been below the GLWQA specific objective of 1.0 ppm for both species since 1977.

The temporal trends in total DDT burdens in young-of-the-year spottail shiners from Leamington and Big Creek are similar those in walleye (Figure 29). According to Suns *et al.* (1985) spottail shiners from Lake Erie had significantly lower residues of DDT in 1982 and 1983 than in 1976 and 1978. However, there was an increase in total DDT levels in spottail shiners from Leamington in 1986.

Spatial Distribution:

Concentrations of total DDT in spottail shiners were below the GLWQA specific objective at all locations at which fish were sampled. The highest concentration was found in samples collected in 1979 from Port Rowan (0.054 ppm).

TABLE 16. MEAN CONCENTRATIONS OF TOTAL DDT IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE ERIE (ppm, wet weight)

Location	Year	Mean DDT Concentration
Big Creek	1982	0.002
Leamington	1983	0.013
Port Rowan	1979	0.054
Port Stanley	1983	0.023
Centre Creek	1983	0.022
Nanticoke Creek	1982	0.009
Grand River	1982	0.005
Thunder Bay	1983	TR

TR = trace detected

Source: K. Suns, Ontario Ministry of the Environment

Dioxins and Furans

Figure 16 and 17 show that total PCDD and PCDF levels in whole walleye were between 10 ppt and 50 ppt in fish from both the eastern and western basins of Lake Erie. High concentrations of PCDD were also found in fish from the Black and Cuyahoga Rivers. Both these rivers are Areas of Concern.

Chlordane

A spottail shiner sample from Port Rowan contained the highest chlordane concentration (0.023 ppm in 1979) on Lake Erie (Table 17). Temporal data on spottail shiners from Leamington show that the highest concentration occurred in 1977. Since then, levels have decreased substantially.

Total Lead

Temporal Trends:

Total lead burdens in rainbow smelt from Lake Erie were below the minimum detection limit (0.01 ppm), except in 1980 when the mean concentration was 0.21 ppm (Figure 30).

Spatial Distribution:

Fish species from four locations in Lake Erie have been analysed to determine total lead burdens (Table 18). Concentrations were between 0.10 and 0.20 ppm and were not substantially different in species from different trophic levels. Fish collected from Erieau had the highest lead burdens.

Mercury

Temporal Trends:

Between 1978 and 1986 mercury concentrations in walleye did not decrease (Figure 31). Similarly, mercury burdens in rainbow smelt did not change over this time. Mercury biomagnifies up the food web and this is reflected in the higher levels in walleye. Concentrations in both species are considerably less than the GLWQA specific objective of 0.5 ppm.

It is impossible to determine temporal trends in spottail shiners

TABLE 17. MEAN CONCENTRATIONS OF CHLORDANE IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE ERIE (ppm, wet weight)

Location	Year	Mean Chlordane Concentration
Big Creek	1982	ND
Leamington	1983	0.003
Port Rowan	1979	0.023
Port Stanley	1983	ND
Centre Creek	1983	TR
Nanticoke Creek	1982	0.004
Grand River	1982	0.002
Thunder Bay	1983	0.003

ND = not detected TR = trace detected
Minimum detection level = 2 ppb
Source: K. Suns, Ontario Ministry of the Environment

TABLE 18. CONCENTRATIONS OF TOTAL LEAD IN FISH (WHOLE BODY) FROM LAKE ERIE (ppm, wet weight)

Location	Species	Mean Total Lead Concentration
Long Point Bay	Northern pike	0.10
	Yellow perch	0.16
	Rainbow smelt	0.11
Erieau	Walleye	0.18
	Yellow perch	0.20
	Rainbow smelt	0.12
Wheatley	Yellow perch	0.16
	Rainbow smelt	0.13
Western Basin	Walleye	0.13
	Yellow perch	0.15
	Rainbow smelt	0.13

Source: P. Hodson *et al.*, 1986b

because there are too many gaps in the data. Concentrations are comparable to those in rainbow smelt.

Spatial Distribution:

The highest mercury burdens in spottail shiners were found in samples collected in 1982 from Big Creek and Thunder Bay (0.061 and 0.049 ppm respectively) (Table 19).

TABLE 19. MEAN CONCENTRATIONS OF TOTAL MERCURY IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE ERIE (ppm, wet weight)

Location	Year	Mean Mercury Concentration
Big Creek	1982	0.061
Point Pelee	1982	0.029
Port Rowan	1979	TR
Port Stanley	1979	0.011
Nanticoke Creek	1982	0.025
Grand River	1982	0.022
Thunder Bay	1982	0.049

TR = trace detected

Source: K. Suns, Ontario Ministry of the Environment

Other Contaminants: Arsenic and Selenium

Arsenic and selenium burdens in fish collected from Lake Erie have varied from year to year. Arsenic levels in walleye fluctuated at approximately 0.35 ppm and concentrations in rainbow smelt fluctuated at approximately 0.2 ppm. Selenium levels were similar in walleye and rainbow smelt and have varied from 0.3 and 0.4 ppm between 1977 and 1987.

2.2.3 Lake Huron

Total PCBs

Temporal Trends:

Total PCB residues in lake trout from Lake Huron have decreased significantly since 1981 (from 1.96 ppm in 1981 to 0.63 ppm in 1987), however, levels are still above the GLWQA objective of 0.1 ppm for whole fish. Between 1979 and 1987 PCB concentrations in rainbow smelt fluctuated at a level slightly above the GLWQA specific objective (Figure 32).

Spatial Distribution:

PCB residues in young-of-the-year spottail shiners from Lake Huron were determined between 1979 and 1981 (see map Figure 33). All concentrations were less than the GLWQA specific objective of 0.1 ppm in whole fish.

Mirex

Mirex was not detected in samples of young-of-the-year spottail shiners from Lake Huron.

Hexachlorobenzene (HCB)

HCB has been detected in fish samples from the Saginaw River and Saginaw Bay, Michigan.

Dieldrin

Temporal trends in dieldrin residues in lake trout are shown in Figure 34. The concentrations show no temporal trend and fluctuated widely between 1980 and 1987. Burdens in rainbow smelt were considerably less than the minimum detection level of 0.01 ppm.

DDT and Metabolites

Temporal Trends:

Total DDT and p,p'-DDE burdens in forage and top predator fish from Lake Huron have been below the GLWQA specific objective of 1.0 ppm since 1979 (Figures 35 and 36). Residues in lake trout have fluctuated significantly over this time and show no obvious trend. Concentrations of total DDT ranged between 0.91 ppm and 0.28 ppm. Concentrations in samples collected in 1986 and 1987 have been the lowest recorded (approximately 0.30 ppm).

Spatial Distribution:

Table 20 shows total DDT burdens in young-of-the-year spottail shiners from eleven sites on Lake Huron. The highest concentration was found in fish from the site on the Nottawasaga River (0.36 ppm) in 1980.

TABLE 20. MEAN CONCENTRATIONS OF TOTAL DDT IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE HURON (ppm, wet weight)

Population	Year	Total DDT Concentration
Blind River	1981	0.033
French River	1979	ND
Sequin River	1979	ND
Thunder Beach	1980	0.025
Nottawasaga River	1980	0.036
Pretty River	1979	0.017
Beaver River	1979	0.009
Saugeen River	1980	0.019
Maitland River	1980	0.013
Ausable River	1980	0.012
Perch Creek	1980	0.008

ND = not detected
Minimum detection level = 1 ppb
Source: K. Suns, Ontario Ministry of the Environment

Dioxins and Furans

Dioxin residues in whole fish from Saginaw Bay were above 200 ppt 2,3,7,8-TCDD. These levels are attributable to industrial discharges to the Tittabawassee River which flows into Saginaw Bay. There are fish consumption advisories on sections of the Tittabawassee River and Saginaw Bay as a result of the high dioxin levels.

There were high levels of furans in fish from two areas of Lake Huron. These were near the mouth of the Spanish River on the North Channel (250 - 300 ppt total PCDF) and Saginaw Bay (250 - 300 ppt total PCDF). Both are Areas of Concern (Figures 16 and 17).

Chlordane

Chlordane concentrations in lake trout from Lake Huron are shown in Figure 37. Between 1978 and 1982 levels equilibrated at just below 0.06 ppm. Chlordane burdens in spottail shiners collected between 1979 and 1981 are shown in Table 21. Detectable levels were found in fish from seven of the eleven sampling sites. The highest concentrations were found in fish from Blind River and Perch Creek in 1981 and 1980, respectively (0.02 ppm).

TABLE 21. MEAN CONCENTRATIONS OF CHLORDANE IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE HURON (ppm, wet weight)

Population	Year	Mean Chlordane Concentration
Blind River	1981	0.02
French River	1979	ND
Sequin River	1979	ND
Thunder Beach	1980	0.01
Pretty River	1979	ND
Beaver River	1979	ND
Nottawasaga River	1980	0.01
Saugeen River	1980	0.01
Maitland River	1980	0.00
Ausable River	1980	0.01
Perch Creek	1980	0.02

ND = not detected

Source: K. Suns, Ontario Ministry of the Environment

Lead

Total lead burdens in fish from Lake Huron are consistently less than 0.1 ppm. Mean concentrations of total lead in offshore fish (whole body measurements) were 0.08 ppm in bloater chub and 0.05 ppm in burbot.

Mercury

Temporal Trends:

There are no obvious trends in mercury burdens in lake trout from Lake Huron. Levels varied between 0.1 and 0.24 ppm (Figure 38). Mercury levels in rainbow smelt were consistently less than 0.1 ppm and in 1987 were less than 0.05 ppm. Levels in both species are considerably less than the GLWQA specific objective of 0.5 ppm for whole fish.

Spatial Distribution:

Mercury burdens in young-of-the-year spottail shiners from Lake Huron have varied from 0.014 ppm in samples from Thunder Beach to 0.05 ppm in samples from the Maitland River (Table 22). Levels of mercury are slightly higher in samples from southern Georgian Bay because the natural background is higher. There are fish consumption advisories on some species of sport fish in this area.

TABLE 22. MEAN CONCENTRATIONS OF TOTAL MERCURY IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM LAKE HURON(ppm, wet weight)

Population	Year	Total Mercury Concentration
Thunder Beach	1980	0.014
Nottawasaga River	1982	0.029
Saugeen River	1980	0.030
Maitland River	1980	0.050
Ausable River	1980	0.020
Perch Creek	1980	0.021

Source: K. Suns, Ontario Ministry of the Environment

Arsenic and Selenium

Arsenic and selenium burdens in forage and top predator fish from Lake Huron are variable and show no temporal trends. The presence of selenium in forage and top predator fish from Georgian Bay is primarily due to the geology of the region. Levels in walleye, smelt and yellow perch are shown in Table 23.

2.2.4. Lake Superior

Total PCBs

Temporal Trends:

PCB burdens in lake trout from Lake Superior have fluctuated since data collection began in 1980, but they have decreased since 1984 (Figure 39). Since 1980, total PCB concentrations in lake trout (age 4+) have been consistently lower than 1.0 ppm in whole fish samples. Concentrations in rainbow smelt have also fluctuated over this time at levels below 0.3 ppm. In 1987, PCB burdens in both species were still above the GLWQA specific objective (0.1 ppm whole fish).

Spatial Distribution:

A 1983 survey showed that PCB concentrations in spottail shiners from Lake Superior were below the 0.1 ppm GLWQA specific objective at all locations sampled except two (Figure 40). The concentration in fish from the Mission River was 0.14 ppm and the concentration in spottail shiners from Peninsula Harbour was 0.159 ppm.

TABLE 23. MEAN CONCENTRATIONS OF SELENIUM IN WALLEYE, SMELT AND YELLOW PERCH FROM GEORGIAN BAY AND THE NORTH CHANNEL (LAKE HURON) (ppm, wet weight)

Species	Location	Year	Mean Concentration (range)
Walleye	Georgian Bay	1973	0.60 (0.42-0.79)
		1980	0.74 (0.57-1.40)
Smelt	Georgian Bay South	1979	0.64 (0.59-0.73)
	Georgian Bay North	1980	0.77 (0.60-0.88)
Yellow Perch	North Channel	1973	0.63 (0.59-0.67)
	Georgian Bay	1973	0.94 (0.77-1.11)

Source: P.V. Hodson *et al.*, 1984a.

Hexachlorobenzene (HCB) and Mirex

HCB and mirex were not detected in young-of-the-year spottail shiners collected from eight sites on Lake Superior in 1983. The minimum detection levels were 0.1 ppm.

Dieldrin

Temporal Trends:

Dieldrin levels in lake trout from Lake Superior decreased between 1980 and 1987 (Figure 41). The mean concentration in lake trout collected in 1987 was 0.02 ppm. Dieldrin levels in rainbow smelt decreased in 1982 and have been less than 0.01 ppm since then.

Temporal Trends:

Total DDT burdens in forage and top predator fish from Lake Superior decreased steadily from 0.38 ppm in 1981 to 0.09 ppm in 1985. Although residue levels have fluctuated slightly, since 1983 they have equilibrated between 0.1 and 0.15 ppm (Figure 42). This equilibrium is probably dependent on atmospheric deposition to Lake Superior. Eisenreich *et al.* (1981) estimated that the atmospheric deposition of DDT to Lake Superior was approximately 0.50 tonnes/year (this is more than three orders of magnitude greater than the estimated atmospheric deposition to Lake Ontario). There are also direct inputs of PCBs to Lake Superior at Peninsula Harbour and St. Louis River.

TABLE 24. TEMPORAL TRENDS IN CONCENTRATIONS OF TOXAPHENE IN LAKE TROUT FROM LAKE SUPERIOR (ppm, wet weight)

Year	Mean Fish Age (Years)	Mean Toxaphene Concentration
1980	5.9	1.9
1983	8.0	2.2
1984	7.0	1.7
1985/6	5.3	1.0

Source: Department of Fisheries and Oceans

Levels of p,p'-DDE, the main metabolite of DDT, have shown the same temporal trends (Figure 43). Concentrations of both compounds are below the GLWQA specific objective of 1.0 ppm for whole fish. Between 1981 and 1987, levels of total DDT and p,p'-DDE in rainbow smelt decreased slightly.

Spatial Distribution:

Levels of total DDT have been determined in spottail shiner samples collected from eight locations on Lake Superior in 1983. The highest concentration was found in fish from Kaministiquia River (0.010 ppm).

Dioxins and Furans

Mean levels of total PCDD in lake trout collected from several locations in Lake Superior were less than 10 ppt. Total PCDF levels were 20 ppt (Figures 16 and 17).

Toxaphene

It is difficult to assess the temporal trends in toxaphene burdens in lake trout from Lake Superior because the data are limited and have not been normalized for age (Table 24). The levels exceed concentrations of all other individual organochlorines reported for Lake Superior fish.

Chlordane

Chlordane burdens in lake trout decreased from 1978 (0.402 ppm) to 1982 (0.041 ppm) (Figure 45).

Concentrations of chlordane in all samples of spottail shiners collected in 1983 were non-detectable (< 2 ppb), except for samples from Batchawana Bay where trace levels were found.

Lead

Lead concentrations (as total lead) in whole body samples of Lake Superior fish have been determined for three fish species. Mean total lead concentrations (wet weight) were 0.06 ppm in bloater chub, 0.04 ppm in burbot and 0.04 ppm in lake trout (Hodson *et al.*, 1984).

Mercury

Mercury burdens in forage and top predator fish from Lake Superior decreased from 1980 to 1985. Since then, there has been a slight increase in levels (Figure 44). Mercury concentrations in lake trout in 1987 were 0.23 ppm. This is less than the 0.5 ppm GLWQA specific objective for whole fish. Residues in rainbow smelt fluctuated and showed no clear trends. In 1980, spottail shiners from Thunder Bay had a mean mercury concentration of 0.030 ppm.

Arsenic, Selenium and Zinc

Between 1980 and 1987 there were no temporal trends distinguishable in arsenic and selenium burdens in lake trout and rainbow smelt. Arsenic concentrations fluctuated between 0.25 and 0.35 ppm and selenium concentrations varied between 0.40 and 0.55 ppm in both species. No great differences in concentrations were observed between forage and top predator species. For 1980-1983, zinc burdens in lake trout were approximately 12.5 ppm.

2.2.5 Lake Michigan

Total PCBs

Temporal trends:

Total PCB levels in lake trout from Lake Michigan have decreased significantly (from 22.91 ppm in 1974 to 4.48 ppm in 1984). Most of the decrease occurred from 1975 to 1977. Since then, concentrations have equilibrated (Figure 46). PCB levels in bloaters have also decreased, however, the decrease was not as great. Levels decreased from 5.66 ppm in 1972 to 1.64 ppm in 1986. Despite these improvements, PCB concentrations in both species are considerably above the GLWQA specific objective of 0.1 ppm for whole fish. According to Murphy and Rzeszutko (1977), atmospheric deposition accounted for over 50% of the total PCB loadings to Lake Michigan.

Spatial Distribution:

Several areas in Lake Michigan are contaminated with PCBs. These include the Mastinique River, southern Green Bay, Sheboygan Harbour, Milwaukee Harbour, Waukegan Harbour, Grand Calumet River, Kalamazoo River and White Lake. In most of these, there are fish consumption advisories for PCBs.

Hexachlorobenzene (HCB)

HCB has been detected in shorthead and redhorse suckers, bluegill, carp and northern pike from Milwaukee Harbour. HCB has also been detected in fish populations in the Fox River, southern Green Bay, Grand Calumet River and White Lake.

Dieldrin

From 1969 to 1978, dieldrin burdens in forage and top predator fish from Lake Michigan increased (Figure 47). From 1979 to the mid 1980s, levels decreased as a result of the restrictions on the use of dieldrin which were implemented in 1974. Dieldrin levels in the two species (lake trout and bloater) are not substantially different from each other. From 1980 to the end of the study period, levels were higher in bloater than in lake trout. From 1976 to 1981, dieldrin burdens in both species exceeded the 0.3 ppm GLWQA specific objective. Levels below the specific objective were last measured in 1986 for bloater (0.2 ppm) and in 1984 for lake trout (0.12 ppm). High levels of dieldrin were detected in fish samples from the Milwaukee Harbour and the Grand Calumet River.

DDT and Metabolites

Total DDT burdens in fish samples from Lake Michigan decreased gradually from 1971 to the end of the study period (from 9.94 ppm in 1969 to 0.67 ppm in 1986 for bloater, and from 19.19 ppm in 1970 to 2.22 ppm in 1984 for lake trout), although an equilibrium may have been established at the end of the study period (Figure 48). The 1984 DDT burdens in lake trout are above the IJC specific objective of 1.0 ppm, however, current levels may be lower.

DDT has been detected in fish from Sheboygan Harbour, Milwaukee Harbour and White Lake. p,p'-DDE and p,p-DDD were detected in fish samples from the Grand Calumet River/Indiana Harbour Canal.

Dioxins and Furans

There is limited information available on dioxin burdens in fish from Lake Michigan. Figures 16 and 17 show the locations of dioxin contamination in the Great Lakes. Although there are four locations where 2,3,7,8-TCDD levels in fish were 10 ppt or less, there are two areas in Lake Michigan where concentrations exceeded 200 ppt (samples from sites near White and Muskegon Lakes). Total PCDF concentrations in fish from a site close to Saugertuck (southeastern Lake Michigan) were between 70 and 160 ppt. More recent data (DeVault, 1984) show that PCDD and PCDF levels were above 10 ppt in samples from several locations.

Chlordane

In 1978-79, Chlordane burdens decreased in lake trout from Lake Michigan. Since then, they have equilibrated at between 0.04 and 0.06 ppm (Figure 49).

Polynuclear Aromatic Hydrocarbons (PAHs)

PAHs have been detected in fish from the Fox River, southern Green Bay and Milwaukee Harbour.

Mercury

High mercury levels have been found in fish samples from Sheboygan Harbour, Milwaukee Harbour, Muskegon Lake and White Lake.

Chlordane

Chlordane residues were detected in fish from the Sheboygan Harbour and high levels were found in fish from the Milwaukee Harbour.

2.2.6 Connecting Channels

ST.CLAIR - DETROIT RIVER SYSTEM

Total PCBs

Temporal trends:

Spottail shiner collection sites in the St. Clair and Detroit Rivers are shown in Figure 50. PCB burdens in spottail shiners from Pike Creek and Lake St. Clair decreased between 1978 and 1983 (Figure 51). Samples collected in 1983 contained levels below 0.05 ppm and therefore, below the 0.1 ppm GLWQA specific objective for whole fish.

Spatial Distribution:

Suns *et al.* (1985) measured PCBs in spottail shiners collected from several locations in 1982 and 1983. Seven of the twelve samples shown in Table 25 contained residue levels above the GLWQA specific objective for whole fish. The highest concentrations occurred in fish from the Sturgeon Bar (3.00 ppm in 1982) and Celeron Island (1.71 ppm in 1983).

TABLE 25. CONCENTRATIONS OF TOTAL PCBS IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. CLAIR - DETROIT RIVER SYSTEM (ppm, wet weight)

Location	Year	Mean Total PCB Concentration
Sarnia	1983	0.15
South Channel	1982	0.07
Chenal Ecarte	1983	0.06
Michell Bay	1982	0.03
Thames River	1982	0.03
Pike Creek	1983	0.03
Turkey Creek	1983	0.32
Grassy Island	1983	0.91
Fighting Island	1983	0.29
Amherstburg	1983	0.15
Celeron Island	1983	1.71
Sturgeon Bar	1982	3.00

Source: K. Suns, Ontario Ministry of the Environment

There are fish consumption advisories on the St. Clair and Detroit Rivers because of PCB contamination in such species as carp and shad. There are also advisories on larger sizes of walleye, freshwater drum and rockbass in the Detroit River.

Mirex

Mirex was not detected in any samples of spottail shiners collected from sites on the St. Clair - Detroit River System.

DDT and Metabolites

Temporal Trends:

Total DDT concentrations varied between 1979 and 1983 in spottail shiners from Pike Creek and Lake St. Clair (Figure 51). During this period, levels were below the GLWQA specific objective for whole fish (1.0 ppm).

Spatial Distribution:

In 1982 and 1983, no samples of spottail shiners contained total DDT burdens exceeding the GLWQA specific objective (Suns *et al.*, 1985) (Table 26).

TABLE 26. MEAN CONCENTRATIONS OF TOTAL DDT IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. CLAIR - DETROIT RIVER SYSTEM (ppm, wet weight)

Location	Year	Mean Total DDT Concentration
Sarnia	1983	0.016
Stag Island	1983	0.004
South Channel	1982	0.010
Chenal Ecarte	1983	0.004
Mitchell Bay	1982	0.002
Pike Creek	1983	0.010
Turkey Creek	1983	0.012
Grassy Island	1983	0.021
Fighting Island	1983	ND
Amherstburg	1983	0.022
Celeron Island	1983	0.022
Sturgeon Bar	1982	ND

ND = not detected

Source: K. Suns, Ontario Ministry of the Environment

Hexachlorobenzene (HCB)

HCB was detected in eleven of twelve spottail shiner samples collected from the St. Clair - Detroit River System in 1982 and 1983. Concentrations ranged from less than the minimum detection level to 0.231 ppm. The highest HCB burden was detected in samples collected in 1983 from Sarnia (0.231 ppm) (Table 27). HCB was also detected in other fish species from Lake St. Clair.

Polynuclear Aromatic Hydrocarbons (PAHs)

PAH concentrations have been determined in fillets of fish from the Detroit River (Harlow and Hodson, 1988). The mean concentration of benzo(a)pyrene was 0.1 ppt in carp and 17.3 ppt in pike.

Mercury

Temporal Trends:

The main sources of mercury to the St. Clair - Detroit River system are industrial chemical facilities. Current loadings are significantly lower than the historical inputs. These were mainly from chlor-alkali plants. Since 1970, mercury burdens in walleye (dorsal muscle tissue) from Lake St. Clair have decreased and have equilibrated just below 0.5 ppm (Figure 52). 1987 was the first year since the study period began (1970) that concentrations were less than the 0.5 ppm GLWQA specific objective. Mercury levels in fish have decreased considerably in the Detroit River. This is a result of control measures applied to point source discharges.

Spatial Distribution:

Mercury burdens in samples of spottail shiners collected from the St. Clair - Detroit River system in 1982 had concentrations between 0.018 and 0.081 ppm (Table 28). The highest concentration was found in samples from the Main Channel (0.081 ppm).

TABLE 27. MEAN CONCENTRATIONS OF HCB IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. CLAIR - DETROIT RIVERSYSTEM (ppm, wet weight)

Location	Year	Mean HCB Concentration
Sarnia	1983	0.231
Stag Island	1983	0.007
South Channel	1982	0.013
Chenal Ecarte	1983	0.010
Mitchell Bay	1982	0.001
Pike Creek	1983	ND
Turkey Creek	1983	0.004
Grassy Island	1983	0.004
Fighting Island	1983	0.004
Amherstburg	1983	0.005
Celeron Island	1983	0.002
Sturgeon Bar	1982	0.005

ND = not detected

Source: K. Suns, Ontario Ministry of Environment

Alkyl Lead

Alkyl lead has been detected in fish from Corunna (St. Clair River) near an alkyl lead production plant (Wong *et al.*, 1988). Average alkyl lead

TABLE 28. MEAN CONCENTRATIONS OF MERCURY IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. CLAIR - DETROIT RIVERSYSTEM (ppm, wet weight)

Location	Year	Mean Mercury Concentration
Main Channel	1982	0.081
Mitchell Bay	1982	0.056
Thames River	1982	0.031
Pike Creek	1982	0.046
Amherstburg	1982	0.052
Celeron Island	1982	0.018
Sturgeon Bar	1982	0.018

Source: K. Suns, Ontario Ministry of the Environment

burdens in whole body carp and white suckers were 0.231 ppm and 0.138 ppm respectively (1984 data). Between 1983 and 1987, burdens of alkyl lead and total lead decreased (Wong *et al.*, 1988).

Chlordane

Table 29 shows chlordane residues in spottail shiners collected in 1982 and 1983. Chlordane is detected in trace amounts in fish from Lake St. Clair. However, in the Detroit River, measurable quantities were found in the six populations studied (concentrations varied from 0.004 to 0.012 ppm).

NIAGARA RIVER

Total PCBs

Suns *et al.* (1985) measured PCB residues in young-of-the-year spottail shiners collected from several locations on the Niagara River in 1982 and 1983 (Figure 53). Total PCBs were above the GLWQA specific objective (0.1 ppm) in nine of the fourteen populations tested (Table 30). PCB burdens varied from 0.005 ppm at the east Welland River in 1983 to 0.87 ppm at the Search and Rescue Station in 1983.

High levels of PCBs were also found in carp (2.0 ppm) from the Tonawanda Channel of the Upper Niagara River and concentrations above 2.0 ppm have been reported in large size American eel, lake trout, chinook salmon, rainbow smelt, coho salmon, white perch and smallmouth bass. As

TABLE 29. MEAN CONCENTRATIONS OF CHLORDANE YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. CLAIR - DETROIT RIVER SYSTEM (ppm, wet weight)

Location	Year	Mean Chlordane Concentration
Sarnia	1983	0.003
Stag Island	1983	ND
South Channel	1982	0.011
Chenal Ecarte	1983	ND
Mitchell Bay	1982	TR
Thames River	1982	TR
Pike Creek	1983	TR
Turkey Creek	1983	0.004
Grassy Island	1983	0.004
Fighting Island	1983	0.004
Amherstburg	1983	0.006
Celeron Island	1983	0.012
Sturgeon Bar	1982	0.010

ND = not detected
TR = trace detected
Source: K. Suns, Ontario Ministry of the Environment

TABLE 30. MEAN CONCENTRATIONS OF TOTAL PCBS IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE NIAGARA RIVER (ppm, wet weight)

Location	Year	Mean Total PCB Concentration
Fort Erie	1983	0.07
Frenchman's Creek	1983	0.06
Strawberry Island	1983	0.06
Wheatfield	1983	0.28
102nd Street	1982	0.51
Cayuga Creek	1983	0.41
Search and Rescue Station	1983	0.87
Usher's Creek	1983	0.07
East Welland River	1983	0.05
West Welland River	1982	0.19
Queenston	1982	0.25
Lewiston	1982	0.18
Peggy's Eddy	1982	0.26

Source: K. Suns, Ontario Ministry of the Environment

a result, there are fish consumption advisories for most species of fish in the river.

Mirex

In 1982-83, mirex burdens in spottail shiners from the Niagara River varied from less than the minimum detection level to 0.009 ppt. Detectable concentrations were found in four of the fifteen populations sampled. In large size American eel, rainbow trout, lake trout, coho salmon and white perch mirex burdens were greater than 0.1 ppt. The GLWQA specific objective for mirex in fish is "substantially absent".

Hexachlorobenzene (HCB)

HCB concentrations in spottail shiners are shown in Table 31. Concentrations vary from less than the minimum detection level at Fort Erie, Strawberry Island and the east Welland River in 1982, to 0.008 ppm in 1982 samples from 102nd Street.

TABLE 31. MEAN CONCENTRATIONS OF HCB IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE NIAGARA RIVER (ppm, wet weight)

Location	Year	Mean HCB Concentration
Fort Erie	1983	ND
Frenchman's Creek	1983	0.001
Strawberry Island	1983	ND
Wheatfield	1983	0.003
102nd Street	1982	0.008
Cayuga Creek	1983	0.005
Search and Rescue Station	1983	0.002
Usher's Creek	1983	TR
East Welland River	1983	ND
West Welland River	1982	0.001
Queenston	1982	0.003
Lewiston	1982	0.007
Peggy's Eddy	1982	0.003

ND = not detected

Source: K. Suns, Ontario Ministry of the Environment

Dioxins and Furans

Levels of PCDFs and 2,3,7,8-TCDD have been determined in spottail shiners. 2,3,7,8-TCDD was detected but the concentrations were low, except in samples from the Cayuga Creek (near Love Canal), where the mean concentration was 59 ppt TCDD. Concentrations of total PCDFs exceeded 200 ppt in fish from all locations sampled and in one location it was greater than 1000 ppt.

DDT and Metabolites

DDT concentrations in all samples of spottail shiners collected in 1982 and 1983 from the Niagara River were below the 1.0 ppm GLWQA specific objective (Table 32). The highest level was in the sample from Queenston (0.061 ppm in 1982).

TABLE 32. MEAN CONCENTRATIONS OF TOTAL DDT IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE NIAGARA RIVER (ppm, wet weight)

Location	Year	Mean Total DDT Concentration
Fort Erie	1983	0.015
Frenchman's Creek	1983	0.024
Strawberry Island	1983	0.023
Wheatfield	1983	0.028
102nd Street	1982	0.018
Cayuga Creek	1983	0.029
Search and Rescue Station	1983	TR
Usher's Creek	1983	0.024
East Welland River	1983	0.018
West Welland River	1982	0.019
Queenston	1982	0.061
Lewiston	1982	0.026
Peggy's Eddy	1982	0.047

TR = trace detected

Source: K. Suns, Ontario Ministry of the Environment

Mercury

Mercury burdens in fish from the Niagara River were above 0.5 ppm (and therefore above the 0.5 ppm GLWQA specific objective) in large white sucker from the Chippawa Channel of the Upper Niagara River. Concentrations in spottail shiners collected in 1982-83 were below this level. The highest concentration found was in the sample from 102nd Street (0.123 ppm in 1982) (Table 33).

TABLE 33. MEAN CONCENTRATIONS OF TOTAL MERCURY IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE NIAGARA RIVER (ppm, wet weight)

Location	Year	Mean Total Mercury Concentration
Fort Erie	1983	0.047
Frenchman's Creek	1983	0.036
102nd Street	1982	0.123
Cayuga Creek	1983	0.052
Search and Rescue Station	1983	0.042
Usher's Creek	1983	0.037
Queenston	1982	0.038
Lewiston	1982	0.038
Peggy's Eddy	1982	0.035

Source: K. Suns, Ontario Ministry of the Environment

Chlordane

Chlordane residues in young-of-the-year spottail shiners are shown in Table 34. Concentrations ranged from less than the minimum detection level to 0.021 ppm in the 1982 sample from Queenston.

ST. LAWRENCE RIVER

Total PCBs

PCB burdens in young-of-the year spottail shiners collected in 1979 and 1983 have been determined by Suns *et al.* (1985). PCB residue levels in the four populations sampled exceeded the 0.1 GLWQA specific objective. In 1983, residues in samples from Grass River were as high as 0.95 ppm (Table 35).

High levels of PCBs were also found in large size channel catfish and sturgeon from the St. Lawrence River below the Moses-Saunders Dam. PCB concentrations exceeded 2.0 ppm in large carp and channel catfish above the dam.

DDT and Metabolites

DDT burdens in spottail shiners have been determined by Suns *et al.* (1985). All samples contained residues below the 1.0 ppm GLWQA specific objective. The highest level was in samples collected in 1979 from Raquette River (0.092 ppm) (Table 36).

TABLE 34. MEAN CONCENTRATIONS OF CHLORDANE IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE NIAGARA RIVER (ppm, wet weight)

Location	**Year**	**Mean Chlordane Concentration**
Fort Erie	1983	ND
Frenchman's Creek	1983	0.003
Strawberry Island	1983	0.004
Wheatfield	1983	0.006
102nd Street	1982	0.015
Cayuga Creek	1983	0.005
Search and Rescue Station	1983	0.005
Usher's Creek	1983	TR
East Welland River	1983	TR
West Welland River	1982	0.01
Queenston	1982	0.021
Lewiston	1982	0.007
Peggy's Eddy	1982	0.008

ND = not detected
TR = trace detected

Source: K. Suns, Ontario Ministry of the Environment

Mirex

Mirex was detected in samples from three of the four spottail shiner populations studied on the St. Lawrence River (Table 37). The GLWQA specific objective for this organochlorine is "substantially absent".

Hexachlorobenzene (HCB)

In 1983, HCB burdens were determined in spottail shiners from three locations. HCB was not detected in the sample from Grass River and in the samples from Cornwall and Maitland the mean concentration was 0.002 ppm.

TABLE 35. MEAN CONCENTRATIONS OF TOTAL PCBS IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. LAWRENCE RIVER (ppm, wet weight)

Location	Year	Mean Total PCB Concentration
Maitland	1983	0.15
Cornwall	1983	0.20
Grass River	1983	0.95
Raquette River	1979	0.38

Source: K. Suns, Ontario Ministry of the Environment

TABLE 36. MEAN CONCENTRATIONS OF TOTAL DDT IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. LAWRENCE RIVER (ppm, wet weight)

Location	Year	Mean Total DDT Concentration
Maitland	1983	0.022
Cornwall	1983	0.025
Grass River	1983	0.006
Raquette River	1979	0.092

Source: K. Suns, Ontario Ministry of the Environment

TABLE 37. MEAN CONCENTRATIONS OF MIREX IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. LAWRENCE RIVER (ppm, wet weight)

Location	Year	Mean Mirex Concentration
Maitland	1983	ND
Cornwall	1983	0.008
Grass River	1983	0.006
Raquette River	1979	0.006

ND = not detected

Source: K. Suns, Ontario Ministry of the Environment

Mercury

The high mercury levels in walleye, northern pike and other fish predator species from the St. Lawrence River below the Moses-Saunders Dam have decreased significantly in recent years. However, they are still above background levels for the area. Concentrations exceed the 0.5 ppm GLWQA specific objective in large size northern pike, smallmouth bass and walleye. Trends in mercury burdens in the dorsal muscle tissue of walleye are shown in Figure 55. Levels have decreased during the study period and appear to have equilibrated between 0.5 and 1.0 ppm since 1978.

Total body burdens in spottail shiners collected in 1979 and 1983 were below the 0.5 ppm GLWQA specific objective (Table 38).

TABLE 38. MEAN CONCENTRATIONS OF MERCURY IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. LAWRENCE RIVER (ppm, wet weight)

Location	Year	Mean Mercury Concentration
Cornwall	1983	0.068
Grass River	1983	0.043
Raquette River	1979	0.039

Source: K. Suns, Ontario Ministry of the Environment

TABLE 39. MEAN CONCENTRATIONS OF CHLORDANE IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM THE ST. LAWRENCE RIVER (ppm, wet weight)

Location	Year	Mean Chlordane Concentration
Maitland	1983	ND
MacDonnell Island	1979	0.009
Cornwall	1983	0.002
Grass River	1983	ND
Raquette River	1979	0.021

ND = not detected
Source: K. Suns, Ontario Ministry of the Environment

Alkyl Lead

Temporal Trends:

Temporal trends in alkyl lead burdens in fish from Maitland are shown in Figure 56. Levels of alkyl lead were highest between 1981 and 1983, with geometric means of 4.21 ppm for carp in 1981 and 3.73 ppm for white sucker in 1983. Subsequently, alkyl lead levels have decreased. This is because of the closure of a nearby alkyl lead plant in 1987 (Wong *et al.*, 1988). There was a similar decrease in total lead concentrations between 1983 and 1986 in fish from the St. Lawrence River, near Maitland (Figure 57).

1984 survey data show that alkyl lead concentrations in whole body of carp and white sucker from the St. Lawrence River near Maitland averaged 3.0 ppm and 3.5 ppm, respectively.

Chlordane

Chlordane burdens in spottail shiners vary from less than the minimum detection level to 0.021 ppm (Table 39).

2.2.7 Discussion

Total PCBs

Where data can be compared, concentrations of total PCBs in whole lake trout are higher in Lakes Ontario and Michigan and lower in Lakes Superior, Huron and Erie (see Table 41 and Figure 58). During the 1970s and early 1980s, there were decreases in mean concentrations of toxic chemicals in whole fish in lake trout from Lakes Michigan and Ontario. Decreases in levels of PCBs in Lake Ontario lake trout were associated with reduced input of PCBs. PCB concentrations in sediments peaked in 1960 (Durham and Oliver, 1983). At present, levels in lake trout have equilibrated. This reflects the cycling of PCBs in the environment. The most important sources of PCBs to the lakes themselves are now indirect and include sediments (Nalepa and Landrum, 1988) and the atmosphere (Murphy and Rzeszutko, 1977). Before restrictions were placed on the use and manufacture of PCBs in 1971, direct inputs from industries and sewage treatment plants were more important. It will be harder to control indirect sources than it was to reduce the direct ones.

Mean residue levels of PCBs in 1982/83 collections of young-of-the-year spottail shiners are shown in Table 40. PCB burdens were highest in Lake Ontario, with fish from eight of the nine sampling sites exceeding the GLWQA specific objective of 0.1 ppm for whole fish. There was also a high mean concentration of PCBs in fish from the Detroit River. This concentration was the second highest overall mean.

Whittle and Fitzsimons (1983) found that concentrations of total PCBs in lake trout, coho salmon and rainbow smelt from Lake Ontario were

TABLE 40. REGIONAL MEANS OF CONCENTRATIONS OF PCBS IN YOUNG-OF-THE-YEAR SPOTTAIL SHINERS FROM 1982/83 COLLECTIONS ppm, wet weight)

Lake or Channel	No. of Sites Sampled	Mean PCB Residues	No. of Sites Where Fish Exceed GLWQA Specific Objective
Lake Superior	9	0.065	2
St. Clair River	3	0.081	1
Lake St. Clair	4	0.038	0
Detroit River	3	0.253	3
Lake Erie West	3	0.227	3
Lake Erie East	4	0.040	0
Niagara River	7	0.116	3
Lake Ontario West	7	0.354	7
Lake Ontario East	2	0.104	1
St Lawrence River	2	0.174	2

Source: K. Suns *et al.*, 1985

significantly ($p < 0.005$) higher than concentrations in the same species from the eastern basin of Lake Erie.

Mirex

Mirex is found in Lake Ontario, the Niagara River and the St. Lawrence River. Concentrations have decreased significantly since the ban on production and use in the mid-1970s. This can be seen in the decreased burdens in whole lake trout. However, like PCBs and DDT, mirex concentrations have reached an equilibrium. This is probably being maintained by sediment remobilization alone because historical sources have been largely eliminated (K. Suns, personal communication). Atmospheric deposition is unlikely to be a significant source (W. Strachan, personal communication).

Hexachlorobenzene (HCB)

HCB is consistently detected in spottail shiners (above 0.001 ppm) from the St. Clair-Detroit River system, the Niagara River, Lake Ontario and the St. Lawrence River. The highest levels have been found in fish from Sarnia. HCB has not been detected in spottail shiners from Lake Superior and Lake Erie. However, it has been detected in other fish species from Areas of Concern, such as Hamilton Harbour, Saginaw Bay and Green Bay.

TABLE 41. CONCENTRATIONS OF CONTAMINANTS IN LAKE TROUT (AGE 4+, WHOLE FISH), 1988 (ppm, wet weight and standard error)

	Ontario	Erie	Huron	Superior
N	46	8	13	8
Weight (g)	1771.38 (47.67)	2436.90 (152.08)	2008.46 (152.63)	1410.29 (120.23)
Lipid (%)	14.83 (0.46)	18.66 (1.08)	17.51 (1.11)	11.23 (0.97)
PCBs	3.39 (0.33)	0.64 (0.17)	1.76 (0.09)	1.96 (0.21)
p,p′-DDE	0.88 (0.06)	0.40 (0.05)	0.30 (0.02)	0.11 (0.01)
DDT and metabolites	1.21 (0.06)	0.49 (0.05)	0.42 (0.03)	0.22 (0.03)
Dieldrin	0.12 (0.01)	0.15 (0.01)	0.05 (0.00)	0.03 (0.00)
Mercury	0.11 (0.00)	0.08 (0.00)	0.09 (0.01) (N=16)	0.13 (0.02) (N = 7)
Mirex	0.20 (0.01)	ND	ND	ND

ND = Not detected
Source: D.M. Whittle, Department of Fisheries and Oceans

Dieldrin

In 1984, lake trout from Lake Ontario had the highest concentrations of dieldrin. Concentrations have not dropped as rapidly as concentrations of other organochlorines although dieldrin burdens in lake trout from Lakes

Ontario and Superior have decreased over time. In contrast, dieldrin levels in lake trout from Lake Huron have varied from year to year.

DDT and Metabolites

Like PCBs, concentrations of DDT in whole lake trout from Lakes Michigan and Ontario decreased significantly between the late 1970s and 1987 (Figure 59). Since the early 1970s, concentrations in samples of whole lake trout from Lakes Superior and Huron have remained at approximately the same low level. This equilibrium may also be a result of remobilization from sediments and atmospheric deposition.

Dioxins and Furans

Dioxins and furans are extremely toxic. Dioxins are found throughout the ecosystem and have a wide geographic distribution in the Great Lakes basin. The distribution of furans in the Great Lakes basin is similar to that of dioxins. This is because they are structurally similar and many sources of dioxins are also sources of furans. Between 1977 and 1987, the concentration of the most toxic congener, 2,3,7,8-tetrachloro-dibenzo-p-dioxin has remained relatively constant in lake trout from Lake Ontario. Love Canal is probably one of the most important sources of this congener to Lake Ontario (Suns *et al.*, 1985). The concentrations of dioxins and furans were highest in fish from Saginaw Bay on Lake Huron.

Oxychlordane

Oxychlordane burdens in lake trout from Lakes Michigan and Superior have decreased to levels similar to those in fish from Lake Huron (0.06 ppm).

Polynuclear Aromatic Hydrocarbons (PAHs)

Benzo(a)pyrene has been detected in fish from Hamilton Harbour and the Detroit River. Samples from Hamilton Harbour contained concentrations between 25 and 50 ppt.

Alkyl Lead

There are two areas in the Great Lakes where fish contain high burdens of alkyl lead. These are near the alkyl lead production plants at

Maitland (St. Lawrence River) and Corunna (St. Clair River). Concentrations of alkyl lead were lower in fish from the St. Clair River than the St. Lawrence River (Wong *et al.*, 1988). The different accumulation patterns are probably a result of differences in the hydraulic regimes of the two areas. The alkyl lead plant at Maitland closed in 1987.

Toxaphene

The use of toxaphene was restricted in Canada in 1971. In the U.S., its manufacture was prohibited in 1982 and its use was banned in 1986. Toxaphene is still used extensively in Central and South America. The most important source to the Great Lakes is atmospheric deposition and it is likely that the toxaphene in the atmosphere originates from these areas. Levels are highest in Lake Superior. This is in contrast to DDT and PCBs. This may be because Lake Superior is oligotrophic (Cohen *et al.*, 1982), and has a large surface area and a slow turnover rate. Contaminants may remain suspended in the water column much longer in Lake Superior than in Lake Ontario because of its low biological productivity. Lake Ontario is mesotrophic and contaminants can become attached to particles and sediment more easily, thus reducing their biological availability.

Mercury

Following the closure of chlor-alkali plants on the Great Lakes, there have been significant decreases in mercury levels in walleye from Lake St. Clair and in fish from other areas influenced by discharges from these plants. Concentrations of mercury in lake trout from Lakes Superior and Ontario and in walleye from Lake Erie have decreased since the late 1970s. In contrast, mercury levels in Lake Huron showed no consistent decrease between 1980 and 1985. Table 41 shows a 'snapshot' of levels of PCBs, p,p'-DDE, DDT, dieldrin and mercury in fish in 1987.

Arsenic, Selenium and Zinc

Arsenic levels in lake trout from Lake Ontario are approximately double those in lake trout from Lakes Erie, Huron and Superior. There have been no temporal trends detected in arsenic levels in fish. Selenium levels in top predator fish from Georgian Bay, Lake Huron were generally higher than

TABLE 42: SUMMARY OF OTHER CONTAMINANTS DETECTED IN FISH FROM THE GREAT LAKES

Parameter	St. Lawrence River	Lake Ontario	Niagara River	Lake Erie	St. Clair-Detroit Rivers	Lake Huron	Lake Michigan	St. Marys River	Lake Superior
Metals									
Antimony				X			X		
Arsenic	X	X	X	X	X	X	X	X	X
Barium						X	X		
Cadmium	X	X	X	X	X	X	X	X	X
Chromium	X	X	X	X	X	X	X	X	X
Cobalt						X	X		X
Copper	X	X	X	X	X	X	X	X	X
Manganese	X	X	X	X	X	X	X	X	X
Molybdenum				X		X	X		
Nickel	X	X	X	X	X	X	X	X	X
Selenium	X	X	X	X	X	X	X	X	X
Silver						X	X		X
Strontium						X	X		X
Tin						X			
Titanium						X	X		
Vanadium						X	X		X
Zinc	X	X	X	X	X	X	X	X	X
Organic Contaminants									
Aldrin	X	X	X	X	X	X	X	X	X
Endrin	X	X	X	X		X	X		X
Alpha-BHC		X	X	X	X	X	X	X	X
Beta-BHC		X	X	X	X		X		
Lindane	X	X	X	X	X	X	X	X	X
Chlordane	X	X	X	X	X	X	X	X	X
Heptachlor	X	X	X	X	X	X	X	X	X
Heptachlor epoxide			X	X	X	X	X		X
Octachlor epoxide		X					X		X
Nonachlor		X	X	X	X	X	X	X	X
Methoxychlor					X	X	X		X
Endosulphan			X	X			X		
Dacthal			X	X		X	X	X	X
Trifluralin				X			X		
Pentachlorophenyl methyl ether		X		X		X	X		
Diazinon				X			X		
Photomirex		X	X						
Polybrominated biphenyl						X			X
Xytron							X		
Chlorobenzenes	X	X	X	X	X	X	X	X	X
Chlorostyrenes	X	X	X	X	X	X		X	X
Chlorobutadienes		X	X	X	X	X			X
Tetrachloropropene				X					
Pentachloropropane				X					
Pentachloronorbornene				X					
Dibutyl phthalate						X			X
Diethylhexyl phthalate						X	X		X
Diethyl phthalate						X			X
Methylbenzothiophene						X			
Chloroanisoles			X			X		X	X
Chlorophenols		X	X	X		X			
Chloroethanes		X	X		X				
Chlorotoluenes			X			X			
Isophorone							X		
Phenol							X		
Chloroterphenyls						X			
Chlorinated diphenyl ethers	X	X				X			
Naphthalene		X			X	X	X		X

TABLE 42: CONTINUED

Parameter	St. Lawrence River	Lake Ontario	Niagara River	Lake Erie	St. Clair-Detroit Rivers	Lake Huron	Lake Michigan	St. Marys River	Lake Superior
Methyl naphthalenes		X			X	X	X		X
Biphenyl		X			X	X			
Methyl biphenyl							X		
Acenaphthene		X			X				
Fluorene		X			X				
Anthracene		X			X		X		X
Phenanthrene		X			X	X	X		X
Phenyl naphthalene		X			X				
Methyl phenanthrene		X			X	X			
Methyl anthracenes		X			X				
Fluoranthane		X			X		X		
Pyrene		X			X		X		
Benzofluorenes		X			X				
Chrysene		X			X				
Perylene		X			X				
Coronene		X			X				
Dibenzo(a,h)anthracene		X			X				
Benzo(k)fluoranthene					X				

1 Based on Copeland *et al.* (1973), Konasewich *et al.* (1978), Clark *et al.* (1984), Niagara River Toxics Committee (1984), DeVault (1985), Jaffe *et al.* (1985), Smith *et al.* (1985), Suns *et al.* (1985), Jaffe and Hites (1986), Camanzo *et al.* (1987), St. Amant *et al.* (1987), Harlow and Hodson (1988), Johnson (1988).

those in top predator fish from Lakes Ontario, Erie and Superior. This is because of a geological anomaly in Georgian Bay. There are also year to year variations in the data. Zinc levels in top predator fish from Lakes Ontario, Erie and Superior were generally comparable and showed no apparent temporal trends.

Table 42 is a compilation of recent results on other metallic and organic contaminants in fish from the Great Lakes and connecting channels.

Fish from Lakes Ontario and Michigan often have higher contaminant burdens than those from Lakes Erie, Huron and Superior. Contaminant levels in fish from Lakes Ontario and Michigan were much higher in the past than they are now. Levels of total PCBs and total DDT in fish from Lakes Ontario and Michigan decreased significantly during the 1970s. Concentrations of mirex in fish from Lake Ontario and alkyl lead in fish from the St. Clair and St. Lawrence Rivers have also decreased significantly. There have been slight decreases or no obvious trends in levels of other contaminants, such as mercury, dieldrin, dioxins, furans, HCB and benzo(a)pyrene. In some cases, there are insufficient data available to discern any trends.

3. BIOACCUMULATION, BIOMAGNIFICATION AND BIOCONCENTRATION

Most species have evolved behaviourial or metabolic mechanisms to extract various essential trace elements and compounds selectively from the environment. Bioconcentration factors vary according to the availability of the elements and compounds and the organism's position in the food web which may vary during the life cycle. The concentrations of elements and compounds required for normal metabolic functioning are probably related to trophic level and habitat. They vary considerably between species.

If there is an excess of a trace element or compound, excretion and depuration may occur. If the process of accumulation of biologically available elements exceeds elimination or degradation, concentrations may increase to toxic levels.

Many of the chemicals that have been discharged to the Great Lakes are not essential and exposure to excessive concentrations can cause health effects in organisms. Industrial processes have synthesised many new non-essential compounds and their ability to bioconcentrate is due to their physical-chemical properties alone because insufficient time has elapsed for the evolution of selective extraction and depuration processes for them.

Aquatic organisms accumulate environmental contaminants through uptake of food and water. The processes of contaminant accumulation can be defined as:

a) Bioaccumulation - the uptake and retention of environmental contaminants from food and the environment;
b) Biomagnification - the magnification (increase in concentration) of environmental contaminants at successively higher trophic levels; and,
c) Bioconcentration - the increase in concentrations of contaminants from the environment (e.g., water, sediments) to the target organisms.

The methods and kinetics of contaminant uptake are different in different aquatic organisms. There are considerable variations between species and within species. This depends on factors such as exposure history, developmental stage and feeding pattern.

Bottom-feeding fish exposed to contaminated sediments have higher contaminant burdens than those exposed to uncontaminated sediments. They also have higher burdens than pelagic fish which feed in the water column. For example, the stomach contents of a white sucker from an area with high levels of PAH in the sediments had a more complex mixture of PAHs and higher levels of such compounds as benzo(a)pyrene, benzanthracene and benzo(k)fluoranthene than did stomach contents of white suckers from two relatively uncontaminated areas (Maccubin *et al.*, 1985). It was concluded that a proportion of white sucker exposure to PAHs could be from the ingestion of contaminated food (see Volume II, Part 2 of this report).

There are several routes through which aquatic organisms are exposed to contaminants, including the ingestion of contaminated sediments, food and water and gill transfer. These routes are likely to contribute variable amounts of contaminants to body burdens. There is conflicting information on the relative importance of these pathways in the bioaccumulation of organochlorine pesticides in fish.

Numerous studies have shown that contaminant burdens in aquatic organisms, particularly fish, are dependent on the duration of exposure (i.e., age). Figure 60 shows the correlation between uptake and age for PCBs and DDT.

Biomagnification occurs if the concentration of a contaminant increases at successively higher trophic levels. However, well-defined trophic levels do not always exist in aquatic ecosystems and a species may occupy several trophic levels due to different feeding habits at different stages of its life cycle. Most metals do not biomagnify appreciably in aquatic ecosystems, although there is some evidence that biomagnification factors for organomercury can exceed 10^3. In contrast to metals, most chlorinated organic contaminants do biomagnify. Biomagnification factors for PCBs in the Lake Ontario ecosystem have been estimated at between 10^5 and 10^6.

4. FISH CONSUMPTION GUIDELINES AND ADVISORIES

Although contaminant levels in water are generally very low, they can be much higher in fish because of bioaccumulation and biomagnification. Concentrations in fish can make them unsuitable for consumption by humans and wildlife because of the possibility of adverse health effects.

Organochlorine contaminants, such as pesticides and PCBs, accumulate in fatty tissues. As indicated earlier, many studies have shown a direct relationship between an organism's lipid content and its contaminant burden. Fish species with low levels of lipid, such as yellow perch and northern pike, are likely to have lower burdens of organic contaminants than fatty species, such as carp, catfish, salmon and trout. In addition, the lipid content of a given species increases with age. Figure 61 shows how age and lipid content are related and how the two factors relate to organochlorine contaminant levels. Table 43 describes the relationship between age, exposure period and contaminant uptake for PCBs, DDT and mercury in walleye from Lake Erie.

The problem of trace inorganic and organic contaminants in the edible portions of sport and commercial fish in the Great Lakes has been recognized for almost 20 years and many jurisdictions in the Great Lakes basin have established guidelines and advisories to protect human consumers and fish eating birds. These guidelines and advisories are discussed in section 3 of Volume II. The U.S. Food and Drug Administration and the Department of Fisheries and Oceans in Canada monitor samples of commercially caught fish to ensure compliance of marketed fish with the relevant objectives and advisories.

Samples of fish are analyzed for a variety of heavy metals, pesticides and trace organic chemicals. Table 44 lists the contaminants for which samples are routinely analyzed by the agencies in the Great Lakes basin (Johnson, 1988).

TABLE 43. MEAN CONCENTRATIONS OF PCBS, DDT AND MERCURY IN SIX AGE GROUPS OF WALLEYE FROM THE WESTERN BASIN OF LAKE ERIE (ppm, wet weight ± standard error)

YEAR	AGE GROUP (sample size)[1]							
	0	1	2	3	4	5	6	7
PCB[2]								
1978				2.13 ± 0.3 (23)		2.08 ± 0.36 (4)		
1979		0.96 ± 0.22 (4)	1.56 ± 0.12 (8)	2.80 ± 0.85 (3)	3.60 ± 0.49 (8)	5.73 ± 1.20 (4)		
1980		0.50 ± 0.06 (5)	1.11 ± 0.14 (10)	1.52 ± 0.17 (14)	1.70 ± 0.38 (4)	2.00 ± 0.49 (5)		
1981	0.53 ± 0.03 (3)	0.83 ± 0.18 (8)	1.09 ± 0.14 (12)	0.92 ± 0.21 (9)	1.26 ± 0.12 (5)			
1982	0.58 ± 0.09 (6)		1.40 ± 0.30 (4)	1.34 ± 0.21 (5)	1.72 ± 0.31 (6)	2.50 ± 0.34 (7)		
1983		0.76 ± 0.08 (10)		1.78 ± 0.20 (8)	1.58 ± 0.20 (12)	2.12 ± 0.15 (5)		
1984		1.34 ± 0.15 (9)	0.52 ± 0.04 (15)	0.48 ± 0.07 (10)	0.83 ± 0.25 (7)	0.54 ± 0.04 (5)		
1985	0.27 ± 0.07 (3)		0.85 ± 0.35 (3)	0.83 ± 0.10 (10)	0.80 ± 0.24 (4)	1.97 ± 0.37 (6)		
1986		0.72 ± 0.03 (10)	1.22 ± 0.11 (5)	1.20 ± 0.20 (3)	1.88 ± 0.28 (13)	1.65 ± 0.18 (13)	4.03 ± 1.96 (3)	1.63 ± 0.2 (3)
1987		-	1.0 ± 0.07 (5)	2.07 ± 0.48 (3)	-	1.50 ± 0.17 (12)	-	-
1988		-	1.16 ± 0.10 (12)	-	1.72 ± 0.25 (9)	1.45 ± 0.16 (16)	-	-
ΣDDT[3]								
1978				0.40 ± 0.05 (23)		0.47 ± 0.10 (4)		
1979		0.10 ± 0.03 (4)	0.20 ± 0.02 (8)	0.44 ± 0.18 (3)	0.59 ± 0.07 (8)	1.06 ± 0.39 (4)		
1980		0.18 ± 0.09 (5)	0.12 ± 0.01 (10)	0.60 ± 0.21 (14)	0.52 ± 0.08 (4)	0.77 ± 0.16 (5)		
1981	0.05 ± 0.01 (3)	0.06 ± 0.01 (8)	0.13 ± 0.02 (12)	0.10 ± 0.02 (9)	0.10 ± 0.04 (5)			
1982	0.06 ± 0.01 (5)		0.23 ± 0.01 (4)	0.29 ± 0.05 (5)	0.28 ± 0.03 (6)	0.34 ± 0.03 (7)		
1983		0.07 ± 0.01 (10)		0.29 ± 0.05 (8)	0.24 ± 0.06 (12)	0.54 ± 0.19 (5)		
1984		0.08 ± 0.01 (9)	0.08 ± 0.02 (15)	0.11 ± 0.01 (10)	0.17 ± 0.02 (7)	0.22 ± 0.05 (5)		
1985	0.02 ± 0.00 (3)		0.07 ± 0.01 (3)	0.11 ± 0.01 (10)	0.13 ± 0.03 (4)	0.16 ± 0.02 (6)		
1986		0.03 ± 0.00 (10)	0.06 ± 0.02 (5)	0.09 ± 0.03 (3)	0.12 ± 0.01 (13)	0.13 ± 0.03 (13)	0.20 ± 0.14 (3)	0.15 ± 0.0 (3)
1987		-	0.06 ± 0.01 (5)	0.06 ± 0.00 (3)	-	0.10 ± 0.01 (12)	-	-
1988		-	0.06 ± 0.01 (12)	-	0.19 ± 0.02 (9)	0.19 ± 0.02 (16)	-	-
Hg[4]								
1978				0.19 ± 0.02 (23)	(4)	0.25 ± 0.10		
1979		0.07 ± 0.01 (4)	0.09 ± 0.01 (8)	0.15 ± 0.04 (3)	0.16 ± 0.01 (8)	0.25 ± 0.08 (4)		
1980		0.06 ± 0.01 (5)	0.07 ± 0.01 (10)	0.14 ± 0.01 (14)	0.19 ± 0.03 (4)	0.20 ± 0.01 (5)		
1981	0.06 ± 0.01 (3)		0.06 ± 0.00 (13)	0.09 ± 0.01 (9)	0.13 ± 0.01 (5)			

TABLE 43. CONTINUED

YEAR	AGE GROUP (sample size)[1]							
	0	1	2	3	4	5	6	7
1982	0.05 ± 0.00 (6)		0.11 ± 0.01 (4)	0.09 ± 0.01 (5)	0.13 ± 0.00 (6)	0.17 ± 0.02 (7)		
1983				0.10 ± 0.01 (8)	0.13 ± 0.02 (11)	0.14 ± 0.03 (5)		
1984		0.08 ± 0.01 (9)	0.08 ± 0.00 (15)					
1985				0.12 ± 0.04 (8)	0.08 ± 0.02 (3)	0.18 ± 0.07 (3)		
1986		0.06 ± 0.00 (10)	0.07 ± 0.01 (5)	0.08 ± 0.01 (3)	0.10 ± 0.00 (13)	0.11 ± 0.01 (13)	0.22 ± 0.09 (3)	0.15 ± 0.0 (3)
1987		-	0.10 ± 0.01 (5)	0.10 ± 0.01 (4)	-	0.12 ± 0.01 (11)	-	-
1988		-	0.06 ± 0.01 (15)	-	0.10 ± 0.02 (6)	0.13 ± 0.02 (9)	-	-

Samples are whole fish.

[1] Only those age groups with a sample size greater than or equal to 3 are considered.

[2] Minimum detection level = 0.1 ppm.

[3] Minimum detection level = 0.01 ppm.

[4] Minimum detection level = 0.03 ppm.

Source: D.M. Whittle, department of Fisheries and Oceans, Unpublished data.

Fish consumption advisories on lake trout and yellow perch can be used to assess changes in consumption advisories over time. Both are important sport and commercial fish species in the Great Lakes. Figures 62 and 63 show the proportion of sites with advisories. There has been a decrease in the number of sites on Lake Huron with advisories for lake trout, however, numbers on Lake Superior and Ontario have remained constant. Between 1983 and 1989, all of the sites on Lake Ontario had advisories for lake trout. Since 1983, there have been no consumption restrictions for lake trout from Lake Erie. However, this species has a limited range and age class in Lake Erie because of thermal restrictions in water temperature and the limited stocking program.

The number of advisories for yellow perch (Figure 63) are lower (except for Lake Erie). This may be because yellow perch occupy an intermediate position in the aquatic food web and have a lower lipid content. The high number of advisories on Lakes Huron and Superior may reflect persistent problems that have not responded to controls on direct sources. The number of advisories for yellow perch has decreased since 1983 and none were issued between 1987 and 1989.

TABLE 44: CONTAMINANTS ROUTINELY ANALYZED IN GREAT LAKES SPORT FISH CONTAMINANT ADVISORY PROGRAMS

Contaminant	Illinois	Indiana	Michigan	Minnesota	New York	Ohio	Pennsylvania	Wisconsin	Ontario
Metals									
Arsenic									X
Cadmium			X						X
Chromium									X
Copper			X						X
Lead			X		X				X
Manganese									X
Mercury			X	X	X			X	X
Nickel			X						X
Selenium									X
Zinc			X						X
Alkyllead									X[1]
Organics									
Aldrin									X
Chlordane	X				X	X	X	X	X
DDT			X		X	X		X	X
Dieldrin			X		X	X		X	X
Dioxin (2,3,7,8-TCDD)			X[1]		X[1]				X[1]
Endrin					X	X			
Heptachlor	X		X		X				X
HCB			X		X	X			X
Lindane					X				X
Mirex				X	X				X
Octachlorostyrene			X						X
PCB	X	X	X	X	X	X	X	X	X
Toxaphene			X[1]			X		X[1]	X

[1] On selected samples.

5. SPORT FISH CONTAMINATION ISSUES

GLWQA specific objectives for whole fish have been developed for four contaminants: DDT and its metabolites (1.0 ppm), mercury (0.5 ppm), mirex (substantially absent) and PCBs (0.1 ppm). Comparison of the most recent contaminant burden data for whole fish with the GLWQA specific objectives shows that there are PCBs in fish from all five Great Lakes (top predator fish only in Lake Erie) and mirex in fish from Lake Ontario (Table 45). This is important for the protection of wildlife, particularly fish-consuming birds, as well as the restriction of the commercial use of whole fish products such as pet food and animal feed.

TABLE 45. SUMMARY OF EXCEEDANCES OF GREAT LAKES WATER QUALITY AGREEMENT SPECIFIC OBJECTIVES, 1986

		Exceedance of Objective[1] for			
Lake	**Fish Species**	**DDT**	**Mercury**	**Mirex**	**PCB**
Ontario	rainbow smelt	X		X	
	lake trout	X		X	X
Erie	rainbow smelt				
	walleye				X
St. Clair	walleye[2]		X		
Huron	rainbow smelt				X
	lake trout				X
Michigan	bloater	X			X
	lake trout	X			X
Superior	rainbow smelt				X
	lake trout				X

1. Exceedance levels are DDT 1.0 ppm, mercury 0.5 ppm, mirex substantially absent and PCBs 0.1 ppm
2. dorsal muscle

Source: Ontario Ministry of the Environment (Lake St. Clair walleye data). Other data from the Department of Fisheries and Oceans.

Johnson (1988) has summarised the main issues in the contamination of Ontario sport fish. Criteria levels refer to Ontario sport fish consumption guidelines and are based on the analysis of skinless dorsal muscle portions.

Lake Ontario

PCB and mirex concentrations in fish exceed the relevant criteria of 2.0 ppm and 0.1 ppm (edible portion) in larger sizes of lake trout, brown trout,

rainbow trout, coho salmon, chinook salmon, American eel, white perch, channel catfish, carp, brown bullhead and gizzard shad. In several cases, mirex is a more limiting contaminant than PCBs.

Mercury concentrations in larger sizes of northern pike, walleye, largemouth bass and channel catfish exceed the 0.5 ppm guideline.

Lake Erie

PCB concentrations in larger sizes of carp and channel catfish in certain western and central basin populations exceed the 2.0 ppm guideline.

Mercury concentrations in the largest sizes of freshwater drum, carp, northern pike, white sucker, white bass, largemouth bass and smallmouth bass exceed the 0.5 ppm guideline.

Lake Huron

PCB concentrations in larger sizes of carp, channel catfish, lake trout, smallmouth bass, rainbow trout, coho salmon, bloater and white sucker exceed the 2.0 ppm guideline in some locations.

Mercury concentrations in larger sizes of walleye, smallmouth bass, white sucker, longnose sucker, channel catfish, carp, coho salmon, yellow perch, freshwater drum, white bass, burbot, northern pike and rainbow trout exceed the 0.5 ppm guideline in some locations.

Lake Michigan

PCB concentrations in certain sizes of lake trout, chinook salmon, coho salmon, brown trout, carp and channel catfish exceed the 2.0 ppm guideline.

Lake Superior

In some locations, PCB concentrations in larger sizes of lake trout, whitefish, white sucker and longnose sucker exceed the 2.0 ppm guideline.

In some locations, mercury concentrations in larger sizes of walleye, whitefish, longnose sucker, white sucker, redhorse sucker, northern pike and lake trout exceed the 0.5 ppm guideline.

In general, mercury contamination of larger sport fish from Lakes Ontario, Erie, Huron and Superior is a natural lake-wide phenomenon reflecting the age, lipid content and trophic status of these fish.

6. FISH CONTAMINATION IN AREAS OF CONCERN

The IJC's Great Lakes Water Quality Board (WQB) has identified specific areas which have serious water contamination problems since 1973. These include harbours, river mouths and connecting channels. They were defined as locations where one or more of the general or specific water quality objectives of the 1978 Great Lakes Water Quality Agreement or jurisdictional standards or criteria were not being met, and where beneficial uses were (or could be) impaired.

One of the criteria used to designate locations as Areas of Concern was the existence of fish consumption advisories. Thirty-six Areas of Concern have fish consumption advisories. Table 46 shows a summary of fish contamination problems in the Areas of Concern.

Based upon the most recent surveillance and monitoring information available, there may be fish contamination at two additional locations: Presqu'ile Bay, Lake Erie at Erie, Pennsylvania, and Black River Bay, Lake Ontario, New York. In 1984, sports fishermen began reporting skin and lip tumours in brown bullheads caught from the Presqu'ile Bay. A U.S. Fish and Wildlife Service survey conducted in 1985 found that 40% of the brown bullheads collected had visible oral and skin abnormalities. High levels of PCBs were also found in whole fish composites of brown bullheads (up to 7.5 ppm), bluegills (up to 4.8 ppm) and bass (up to 7.8 ppm).

The New York Department of Environmental Conservation reported that spottail shiners from Black River Bay contained PCBs at levels ten times higher than fish from other New York waters of Lake Ontario or the international section of the St. Lawrence River, and 30 times higher than fish from New York waters of Lake Erie.

TABLE 46: FISH CONTAMINANT ISSUES IN THE AREAS OF CONCERN

Area of Concern	Health Advisories on Fish	Fish Species Affected	Contaminants of Concern	Specific Details
Lake Superior				
Peninsula Harbour	Yes	Lake Trout Lake Whitefish White Sucker Longnose Sucker Shorthead Redhorse	Mercury, PCB	o Contaminant sources include antecedent discharges of mercury from chlor-alkali plant (closed in 1976) and PCB from electrical generating station. o Steady decline in average mercury and PCB concentrations in lake trout between 1976 and 1985. o Currently, lake trout under 65 cm in length have unlimited consumption status,whereas larger fish designated in limited consumption category. o Occasionally, large lake trout tested have PCB levels somewhat higher than the Health and Welfare Canada consumption objective (2.0 ppm). o Consumption restrictions also on larger sizes of lake whitefish, white sucker, longnose sucker and shorthead redhorse.
Jackfish Bay	Yes	Lake Trout	Mercury	o Fisheries resources and habitat impaired by pulp and paper mill discharges. o Consumption advisory for lake trout over 45 cm. o Lake whitefish and cisco suitable for unlimited consumption. o High mercury levels in fish considered a residual whole-lake problem.
Nipigon Bay	Yes	Yellow Perch	Mercury	o Fisheries resources and habitat impaired by pulp and paper mill discharges. o Consumption advisory for yellow perch over 30 cm. o No consumption limitations for lake whitefish, round whitefish, cisco or lake trout. o Mercury contamination considered a residual whole-lake problem.
Thunder Bay	Yes	Walleye Longnose Sucker White Sucker Northern Pike	Mercury	o Fisheries resources and habitat impaired by discharges from forest products industries. o Limited consumption advisory for northern pike over 55 cm, and walleye, white sucker and longnose sucker over 45 cm.
St. Louis River/Bay	Yes	Shorthead Redhorse Walleye White Sucker Northern Pike	Mercury, PCB	o Contamination primarily due to historical discharges from local industrial and municipal sources. o Health advisories issued for 15-20" shorthead redhorse from the St. Louis River, upstream of Brookston, as well as for 15-20" walleye, 15-20" white sucker and 15-30" northern pike from St. Louis Bay. o Fisheries resources greatly improved since the early 1970s.
Torch Lake	Yes	Walleye, Sauger	-	o Aquatic ecosystem impacted by copper ore tailings. o Fish consumption advisory due to high frequency of tumours.
Deer Lake-Carp Creek/River	Yes	All Species	Mercury	o Mercury sources were two industrial laboratories discharging to sewerage system. o Consumption advisory since 1981 on all fish in Deer Lake and resident fish in Carp Creek and the Carp River downstream to Lake Superior.
Lake Michigan				
Manistique River	Yes	Carp	PCB	o PCB source is contaminated soils eroding from the banks of an old deinking waste settling lagoon of pulp and paper mill. o Consumption advisory for carp caught below the dam in Manistique, Michigan. o This site is listed under the Superfund Program.

TABLE 46: FISH CONTAMINANT ISSUES IN THE AREAS OF CONCERN

Area of Concern	Health Advisories on Fish	Fish Species Affected	Contaminants of Concern	Specific Details
Menominee River	No	-	-	o Heavy recreational fishery use, with a good walleye fishery, although some taste and odour problems have been reported. o Sediments heavily contaminated by arsenic. o Arsenic has been detected in walleye fillets.
Fox River/	Yes	Most Sportfish	PCB	o Over 100 toxic substances were identified in the Southern Green BaySpeciesdischarges to the Lower Fox River from 14 pulp and paper mills and five major municipal wastewater treatment plants. o Since 1972, the area fishery has improved in quantity and diversity but is still impaired. o A regionally renowned walleye fishery has been established below the De Pere Dam. o A good sport and commercial perch fishery exists in the lower bay. o Some fish species historically present, e.g., northern pike, sturgeon and muskellunge, are not found or are found only in limited numbers. o Consumption advisories on lake trout, walleye, brook trout, lake whitefish, northern pike, white sucker, rainbow trout, chinook salmon, coho salmon, brown trout, smallmouth bass and carp. o Closure of commercial carp fishery. o Low or trace levels of industrial chemicals, pesticides and their breakdown products found in fish, including pentachlorobenzene, alpha-BHC, DDT, HCB, nonachlor, pyridine, carboxamide, tri-, tetra- and pentachlorophenols, PAHs, resin acids, furans, dioxins, mercury and other heavy metals.
Sheboygan Harbor	Yes	All Species	PCB	o PCB source is contaminated soil from landfilled dike on industrial property; site remediation under Superfund Program. o Consumption advisory due to PCB for Sheboygan River downstream of the Sheboygan Falls Dam. o Other contaminants detected in fish include DDT, dieldrin, endrin, methoxychlor, lindane, nonachlor, chlordane, mercury, lead and other heavy metals. o PCB-contaminated sediments in the lower Sheboygan River and Harbor are listed under the Superfund Program.
Milwaukee Harbor	Yes	Shorthead Redhorse Bluegill Carp Northern Pike	PCB	o Contaminant sources are industrial and municipal discharges, waste disposal site seepage and agricultural land runoff. o Despite a steady decline over the past ten years, average PCB concentrations in fish from the Milwaukee, Menomonee and Kinnickinnic Rivers and the Milwaukee Estuary remain well above the FDA action level of 5 ppm. o Elevated levels of dieldrin, DDT, chlordane and mercury have also been found in some fish in the lower river. o Other contaminants detected include HCB, alpha-BHC, lindane, nonachlor, PAHs and heavy metals. o Fish surveys indicate a diverse fishery resource is present, e.g., 35 species of which 23 are sport fish (including coldwater salmonids) in the lower Milwaukee River. o The Kinnickinnic River upper estuary is currently being utilized by fishermen during the spring and fall trout and salmon runs.
Waukegan Harbor	Yes	All Species	PCB	o PCB source is contaminated soil on industrial property. o Consumption advisory due to PCB since 1980.

TABLE 46: FISH CONTAMINANT ISSUES IN THE AREAS OF CONCERN

Area of Concern	Health Advisories on Fish	Fish Species Affected	Contaminants of Concern	Specific Details
Grand Calumet River/ Indiana Harbor Canal	Yes	All Species	Chlordane, PCB	o Major contaminant source is in-place pollutants. o Very few resident fish species have been observed, e.g., carp was the only species consistently collected. Other species appear to be transient. o Other contaminants detected include alpha-BHC, HCB, pentachlorophenols, nonachlor, oxychlordane, p,p'-DDD, p,p'-DDE and dieldrin.
Kalamazoo River	Yes	All Species	PCB	o PCB source is historic wastewater discharges from paper industries. o Sediments in approximately 128 km (80 miles) of the Kalamazoo River, between the City of Kalamazoo and the City of Saugatuck (Lake Michigan) are contaminated with PCBs. o Consumption advisory for carp, suckers, catfish and largemouth bass.
Muskegon Lake	No	-	-	o Elevated mercury and PCB levels found in large fish. o Carp over 69 cm from Bear Lake (a tributary to Muskegon Lake) contained more than 2 ppm PCB, the Michigan Department of Public Health (MDPH) action level. o Walleye over 55 cm and largemouth bass over 40 cm from Lake Muskegon had mercury concentrations above the 0.5 ppm action level.
White Lake	Yes	Carp	PCB	o White Lake has an excellent walleye, perch, largemouth bass and northern pike fishery. o Carp had average PCB concentrations of 3.7 ppm, above the MDPH action level of 2 ppm. o Source of PCBs likely atmospheric due to low PCB concentrations in sediments. o Other contaminants detected include DDT, mirex, HCB, hexachlorocyclopentadiene, hexachlorobutadiene, octachloropentene, mercury and other heavy metals.
Lake Huron				
Saginaw River and Saginaw Bay	Yes	Most Sportfish Species	PCB, PBB, Dioxin	o Contaminant sources are industrial and municipal discharges, waste disposal site seepage and agricultural land runoff. o Consumption advisories due to PCB are restricted to bottom-feeding fish, e.g., all carp and catfish from the lower Saginaw River and Saginaw Bay, as well as fish with relatively high levels of body fat, e.g., restricted consumption of lake trout, rainbow trout and brown trout from Saginaw Bay. o No advisories for yellow perch or walleye, the principal sport fish in Saginaw Bay. o Fish consumption bans also occur for portions of the following tributaries: South Branch of the Shiawassee River (PCB); Chippewa River (PBB); Pine River (PBB); Tittabawassee River (PBB, dioxin); and upstream Saginaw River (PBB, dioxin).
Collingwood Harbour	Yes	Yellow Perch	Hg	o Collingwood Harbour has a good all-year-round sport fishery. o Restricted consumption advisory for large yellow perch due to mercury appears to be a regional natural phenomenon for southern Georgian Bay and is not related to any localized source of contamination.

TABLE 46: FISH CONTAMINANT ISSUES IN THE AREAS OF CONCERN

Area of Concern	Health Advisories on Fish	Fish Species Affected	Contaminants of Concern	Specific Details
				o Investigations of contaminants in sportfish in 1984 indicated low concentrations of mercury and essentially no PCBs or mirex accumulations.
Penetang Bay to Sturgeon Bay (Severn Sound)	Yes	Walleye Rainbow Trout White Sucker Smallmouth Bass	Mercury	o Restricted consumption advisory for larger sportfish species, e.g., walleye, smallmouth bass, due to mercury. o Regional natural phenomenon for southern Georgian Bay and is not related to any localized source of contamination.
Spanish River	Yes	Yellow Perch Walleye	Mercury	o Consumption advisories due to mercury in larger yellow perch and walleye. o Mercury concentrations in fish from the Spanish River mouth are similar to those of headwater lakes in the Spanish River system, suggesting a natural regional phenomenon.
Lake Erie				
Clinton River	No	-	-	-
Rouge River	Yes	Carp White Sucker	PCB	o Major contaminant source is in-place pollutants. o Consumption advisory due to high levels of PCBs in carp and white suckers.
Raisin River	Yes	Carp	PCB	o Major contaminant source is in-place pollutants. o Other contaminants detected in fish were DDT, nonachlor, tri-, tetra- and heptadecane, naphthalene, methyl- and dimethylnaphthalene, methylbiphenyl, phenanthrene, fluoranthene, pyrene, pyridine, carboxamide and mono- and dichlorobiphenyl.
Maumee River	No	-	-	o The fishery in the lower Maumee River is impaired. o Fish community is composed primarily of species tolerant of high turbidities, e.g., white perch, carp, yellow perch, white bass, freshwater drum and spottail shiner. o PCB levels in whole body composites were elevated (range of 2.1 to 11.5 ppm). o Other contaminants detected were DDT, DDE, HCB, lindane, dieldrin, chlordane, oxychlordane, nonachlor, methylbiphenyl, methylbenzanthrene, pyridine, carboxamide, pentachloroanisole, heptadecane, nonadecane, heptachlor and heptachlor epoxide.
Black River	Yes	All Species	PAH, PCB	o Major contaminant source is in-place pollutants. o Consumption advisory due to PAH and PCB as well as fish tumors for the lower 8 km of the river. o Carp and brown bullhead had high body burdens of PAH (greater than 1 ppm) and PCBs (close to or exceeding the FDA action level of 2 ppm). o Specific PAHs and other contaminants detected in fish included methylnaphthalene, phenanthrene, benzo(a)pyrene, biphenylphenanthrene, fluoranthene, pyrene, fluorine, acenaphthalene, dibenzothioprene, pyridine, carboxamide, terphenyl, phenylnaphthalene and pentachloroanisole.
Cuyahoga River	No	-	-	o Few fish occur in the lower Cuyahoga River and in Cleveland Harbor due to depressed dissolved oxygen levels, elevated levels of ammonia and polluted bottom sediments. o In 1980, PCB levels in carp, goldfish and white sucker ranged from 1.6 to 23.0 ppm.

TABLE 46: FISH CONTAMINANT ISSUES IN THE AREAS OF CONCERN

Area of Concern	Health Advisories on Fish	Fish Species Affected	Contaminants of Concern	Specific Details
				o The probability of the Cuyahoga River ever having a sport fishery is small; however, with improved water quality and reduced pollutants in the water and sediments, more desirable fish species may start to reappear.
Ashtabula River	Yes	All Species Other Organics	PCB,	o Major contaminant source is in-place pollutants. o Consumption advisory for the lower 3.2 km (2 miles) of the river and harbour. o Total PCBs in fish ranged from 0.68 to 10.66 ppm. o Other chemicals of concern in fish include octachlorostyrene, HCB, hexachloroethane and hexachlorobutadiene.
Wheatley Harbour	No	-	-	o The harbour supports a recreational and bait fish fishery. o Field biomonitoring of PCB uptake by fish indicated PCB levels from below detection to 460 ppb.
Lake Ontario				
Buffalo River	Yes	All Species	Multiple	o Major contaminant source is in-place pollutants. o Surveys in 1977 and 1980 reported levels of PCB, DDT, aldrin/dieldrin, chlordane and mercury in fish were below the FDA standards. o Consumption advisory due to the multiplicity of persistent toxic substances present in fish, including heavy metals; pesticides such as mirex, aldrin/ dieldrin and DDT; dioxin; and industrial organic compounds such as PCBs, chlorobenzenes and PAHs.
Eighteen Mile Creek/ Olcott Harbor	Yes	All Species	Multiple	o Major contaminant source is in-place pollutants. o Contaminants detected in fish were PCB, mirex, DDT, dieldrin, mercury and other heavy metals. o Consumption advisory due to the multiplicity of persistent toxic substances present in fish.
Rochester Embayment	Yes	All Species	Multiple	o Major contaminant source is in-place pollutants. o PCB and pesticide levels in fish from the Lake Ontario nearshore at Rochester were below FDA action levels. o Quantifiable amounts of mirex were found in all fish species. o Consumption advisory due to the multiplicity of persistent toxic substances present in fish.
Oswego River	Yes	All Species	Multiple	o Major contaminant source is in-place pollutants. o Elevated concentrations of mercury, mirex and PCB have been reported for fish from Oswego River and Lake Ontario at Oswego. o No values were extremely high, but the general level of contamination indicates a chronic problem. o Consumption advisory due to the multiplicity of persistent toxic substances present in fish.
Bay of Quinte	Yes	Some Sportfish Species	Mercury, Mirex, PCB	o Acceptable levels of contaminants occur in most fish species and size classes. o Consumption advisories on larger sizes of walleye, northern pike, largemouth bass, American eel, channel catfish and smallmouth bass.
Port Hope Yes		Rainbow Trout Brown Trout	PCB	o Major contaminant source is in-place pollutants. o PCB levels in larger size classes of rainbow trout and brown trout are elevated.

TABLE 46: FISH CONTAMINANT ISSUES IN THE AREAS OF CONCERN

Area of Concern	Health Advisories on Fish	Fish Species Affected	Contaminants of Concern	Specific Details
				o Uranium and thorium series radionuclides have been found in fish tissues; however, based on the levels detected, human consumption of fish taken from the harbour is unlikely to result in an exceedance of the stochastic dose limit recommended for protection of the general public.
Toronto Waterfront	Yes	Some Sportfish Species	Mercury, Mirex, PCB	o Restricted consumption due to PCB and mirex chiefly from sources outside the Toronto Harbour area and due to mercury likely resulting from natural background mercury sources. o Consumption advisories on larger sizes of lake trout, brown trout, carp, white bass, yellow perch, gizzard shad, northern pike, white sucker.
Hamilton Harbour	Yes	Some Sportfish Species	Mirex, PCB	o Contaminant sources are industrial and municipal discharges. o Restricted consumption advisory on larger sizes of white perch, carp, brown trout, freshwater drum and channel catfish.
Connecting Channels				
St. Marys River	Yes	Some Sportfish Species	Mercury	o Consumption advisories on longnose sucker and white sucker, as well as larger sizes of some species (e.g., lake trout, northern pike and walleye) due to mercury, likely arising from upstream (Lake Superior) sources. o Edible portions of sportfish collected in Canadian waters do not contain PCBs, organochlorine pesticides and dioxin above Health and Welfare Canada guidelines. o Detectable levels (ppb) of some PAHs occur in some fish, e.g., white sucker, brown bullhead.
St. Clair River	Yes	Most Sportfish Species	Mercury, Pesticides, PCB	o Contaminant sources include antecedent discharges of mercury from chlor-alkali plant (discharge ceased in 1970), in-place pollutants and industrial discharges. o Michigan consumption advisory for gizzard shad over 25 cm. o Ontario consumption advisories for larger sizes of walleye, white sucker, freshwater drum and yellow perch due to mercury contamination, as well as carp and gizzard shad, due to PCB contamintion. o Mercury levels in the edible portion (skinless, boneless fillet) exhibited a significant decline during the period 1970 to 1985; PCB levels have also declined. o Young-of-the-year spottail shiners and yellow perch collected just below the Sarnia area in 1983 had PCB concentrations of 146 ppb; PCB concentrations declined to 25 ppb in the vicinity of Stag Island; other compounds also detected included chlordane (11 ppb), HCB (231 ppb), and octachlorostyrene (OSC) (560 ppb); the observed concentrations of HCB and OCS were above those commonly found at other Great Lakes sites; the elevated levels of OCS were found to persist downstream to the river delta, whereas the impact of HCB appeared to be more localized.

TABLE 46: FISH CONTAMINANT ISSUES IN THE AREAS OF CONCERN

Area of Concern	Health Advisories on Fish	Fish Species Affected	Contaminants of Concern	Specific Details
Detroit River	Yes	Some Sportfish	Mercury,	o Mercury levels in fish have decreased considerably as a Species PCB result of control measures applied to upstream point source dischargers and because of natural purging of the river system; however, both mercury and PCB levels still elevated, and fish consumption advisories issued by Michigan and Ontario. o Michigan and Ontario consumption advisory due to PCB for all carp. o Ontario consumption advisory on larger sizes of walleye, freshwater drum and rock bass due to elevated levels of mercury, PCBs and other organics.
Niagara River	Yes	Most Sport Species Other Organics	Mercury, Mirex, PCB,	o Contaminant sources are industrial and municipal discharges, waste disposal site seepage and in-place pollutants. o Mercury concentrations above 0.5 ppm in large white sucker from Chippawa Channel of Upper Niagara River. o PCB concentrations above 2.0 ppm in carp from Tonawanda Channel of Upper Niagara River. o PCB concentations above 2.0 ppm in larger sizes of American eel, lake trout, chinook salmon, rainbow trout, coho salmon, white perch, white sucker, channel catfish, freshwater drum, carp and smallmouth bass. o Mirex concentrations above 0.1 ppm in larger sizes of American eel, rainbow trout, lake trout, coho salmon and white perch. o No Ontario advisory on yellow perch, walleye, muskellunge, northern pike, rock bass, brown bullhead, shorthead redhorse, rainbow smelt and white bass. o Commercial fishery for American eel closed. o Numerous organic chemicals of industrial or agricultural origin have been identified in fish, including mirex, dieldrin/aldrin, DDT, dioxin, PCBs, chlorobenzenes and PAHs.
St. Lawrence River	Yes	Some Sport Species	Mercury, Mirex, PCB	o Contaminant sources include antecedent industrial discharges of mercury, PCB and alkyllead. o Elevated mercury levels in walleye, northern pike and other predator species from St. Lawrence River below Moses-Saunders Dam; levels have declined significantly, but remain above background concentrations. o Elevated PCB levels in larger sizes of channel catfish and sturgeon from St. Lawrence River below Moses-Saunders Dam. o Former elevated levels of organic forms of lead in fish from Maitland area of Upper St. Lawrence River. o PCB concentrations above 2.0 ppm in large carp and channel catfish from St. Lawrence River above Moses-Saunders Dam. o Mercury concentrations exceed 0.5 ppm in larger sizes of chiefly predator species such as northern pike, smallmouth bass and walleye. o Ontario consumption advisory for larger sizes of walleye, northern pike, yellow perch, white sucker, smallmouth bass, sturgeon and channel catfish from Lake St. Francis. o Ontario consumption advisory on larger sizes of walleye, brown bullhead, northern pike, black crappie, smallmouth bass, yellow perch, white sucker, white perch and American eel from various sections of the St. Lawrence River between Iroquois and Cornwall.

TABLE 46: FISH CONTAMINANT ISSUES IN THE AREAS OF CONCERN

Area of Concern	Health Advisories on Fish	Fish Species Affected	Contaminants of Concern	Specific Details
				o Ontario consumption advisory for larger sizes of northern pike, carp, brown bullhead, white sucker, smallmouth bass, yellow perch and channel catfish from various sections of the St. Lawrence River upstream of Iroquois. o New York consumption advisory for all species of fish due to multiplicity of persistent toxic substances. o The commercial fishery (carp, white sucker, eel) is impaired due to mercury and PCBs.

Source: IJC (1981, 1983a,b, 1985, 1987a,b)

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LAKE ONTARIO

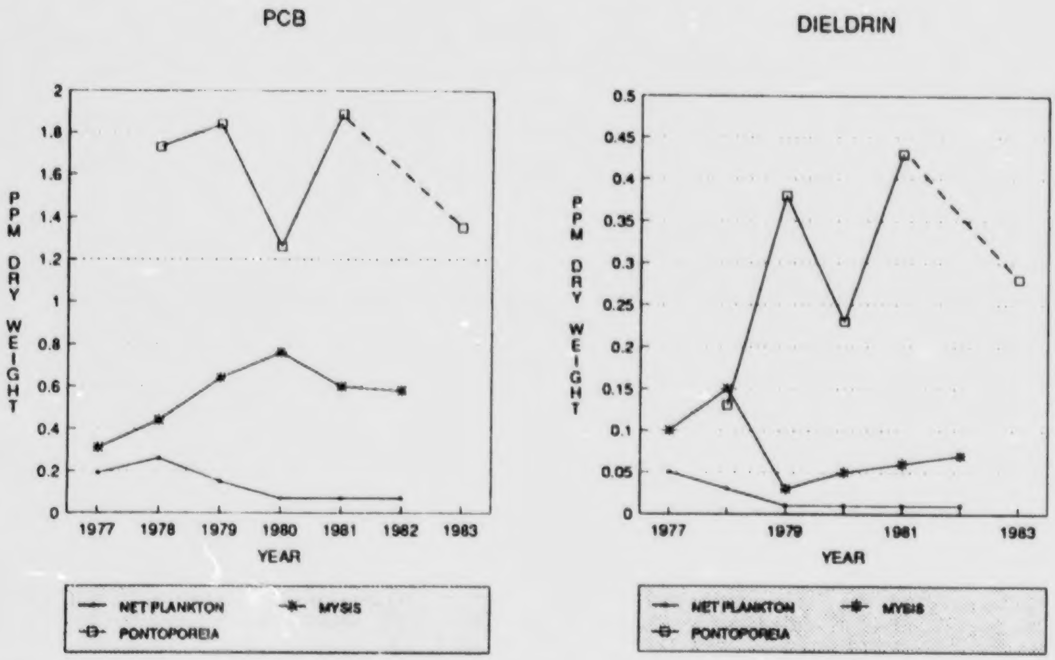


Figure 1

Mean concentrations (ppm dry weight) of organochlorine residues in Lake Ontario invertebrates: plankton, *Mysis* and *Pontoporeia*.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans

LAKE ONTARIO

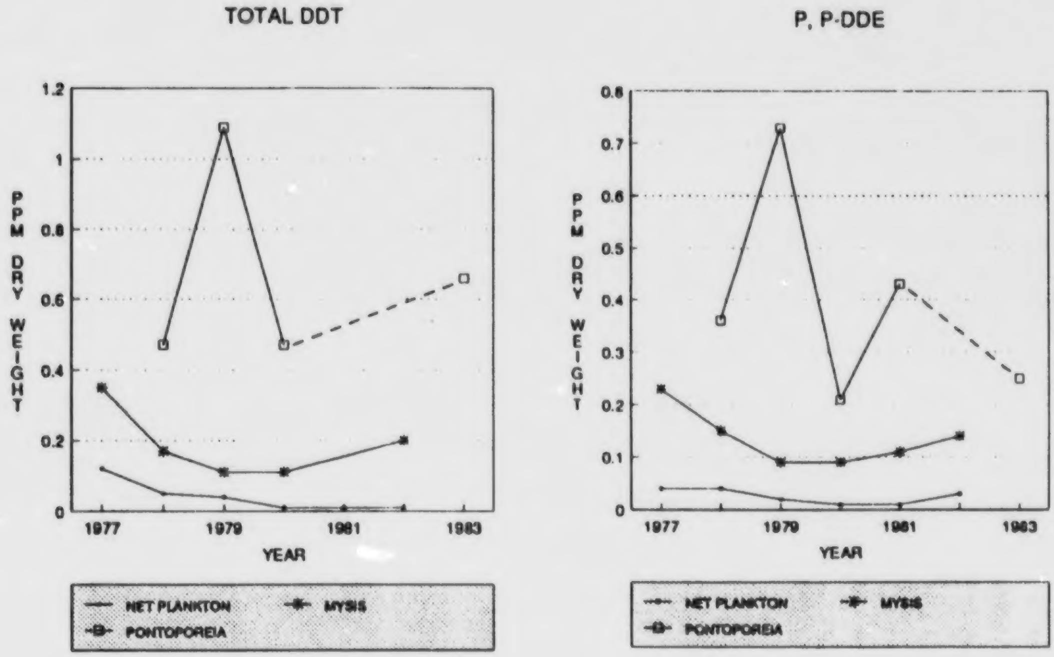


Figure 1 (continued)

LAKE ONTARIO

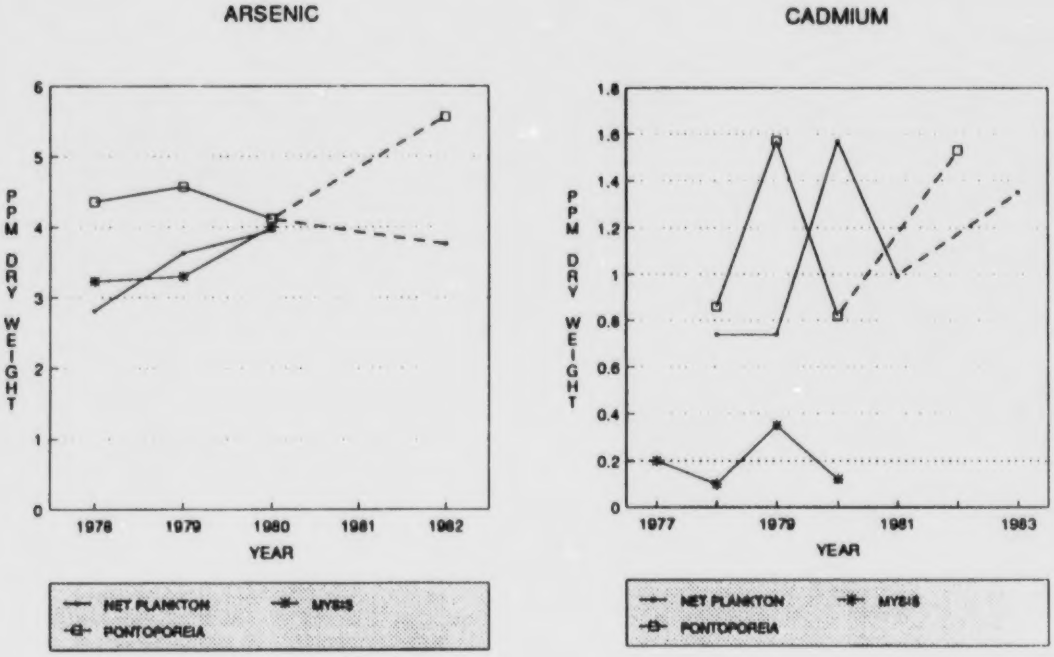


Figure 2

Mean concentrations (ppm dry weight) of heavy metals in Lake Ontario invertebrates.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans

LAKE ONTARIO

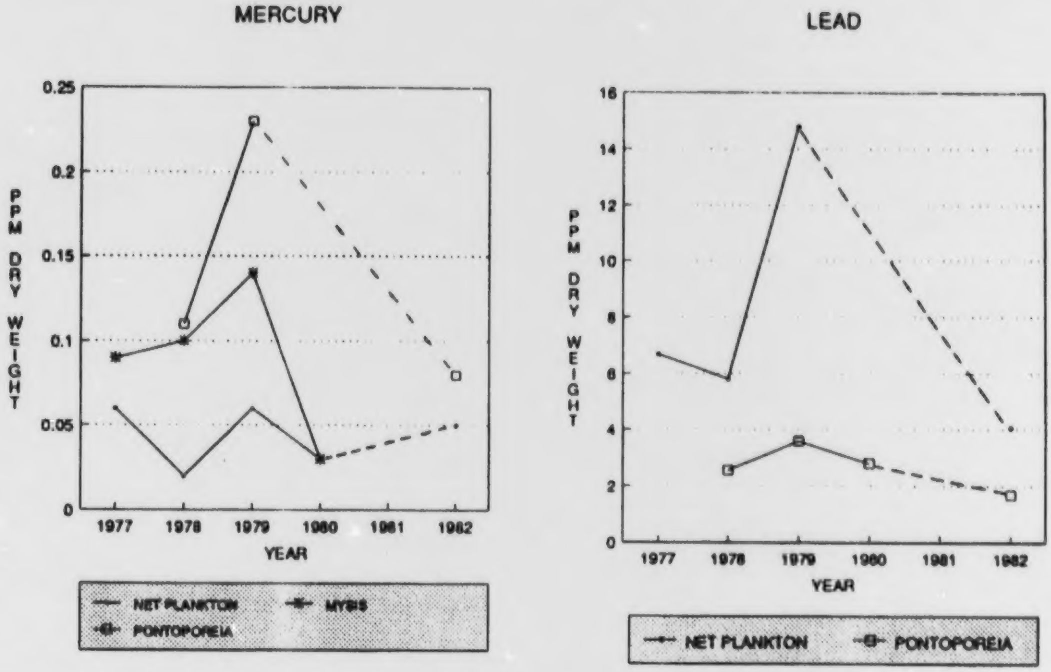
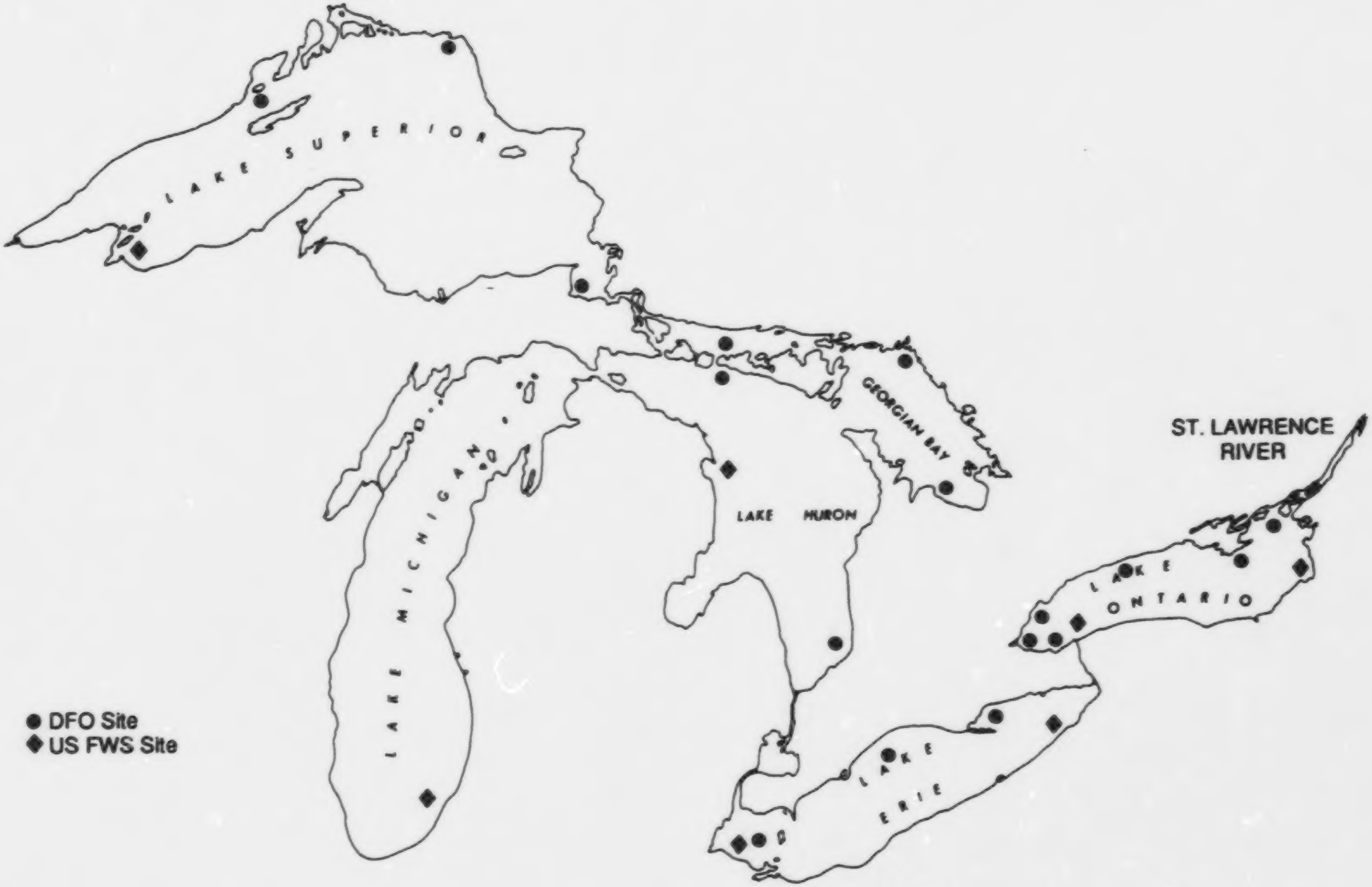


Figure 2 (Continued)



ST. LAWRENCE RIVER
LAKE SUPERIOR
GEORGIAN BAY
LAKE HURON
LAKE MICHIGAN
LAKE ONTARIO
LAKE ERIE
● DFO Site
◆ US FWS Site

Figure 3

Locations of open lake fish collection sites

Note: Open lake species included in this report: lake trout, walleye, rainbow smelt and bloater. Species sampled on the St. Lawrence River include carp, white sucker and brown bullhead.

Source:Department of Fisheries & Oceans and US Fish and Wildlife Service

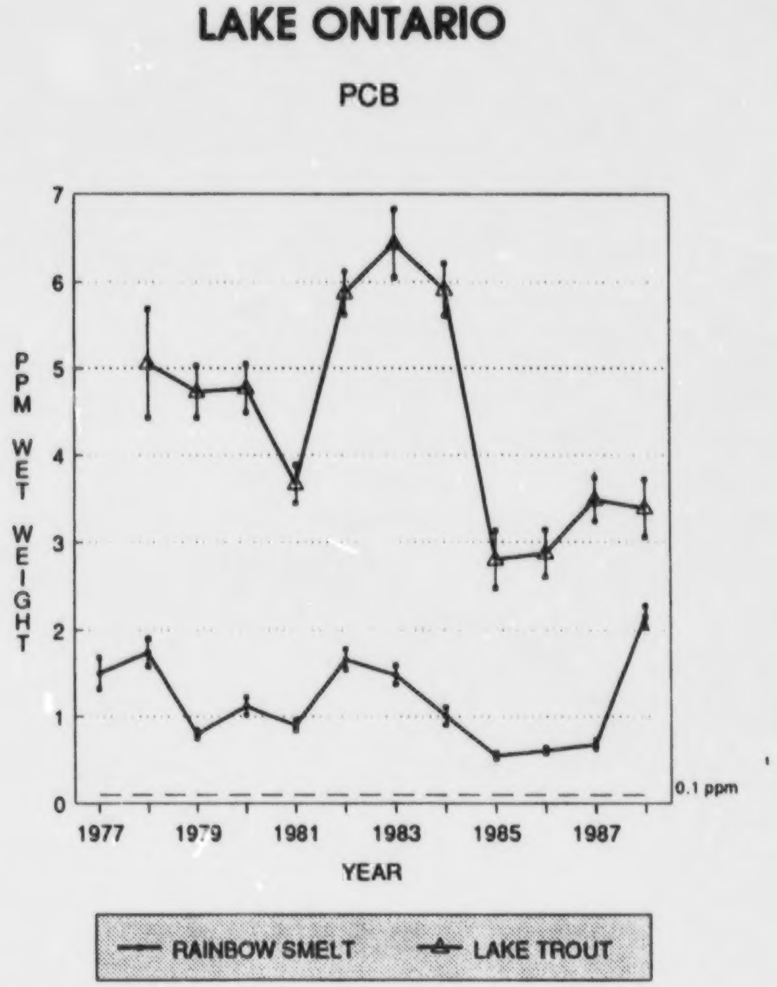


Figure 4

Mean concentrations of PCBs (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Ontario.

1. Great Lakes Water Quality Agreement Objective for whole fish.
Source: Department of Fisheries & Oceans

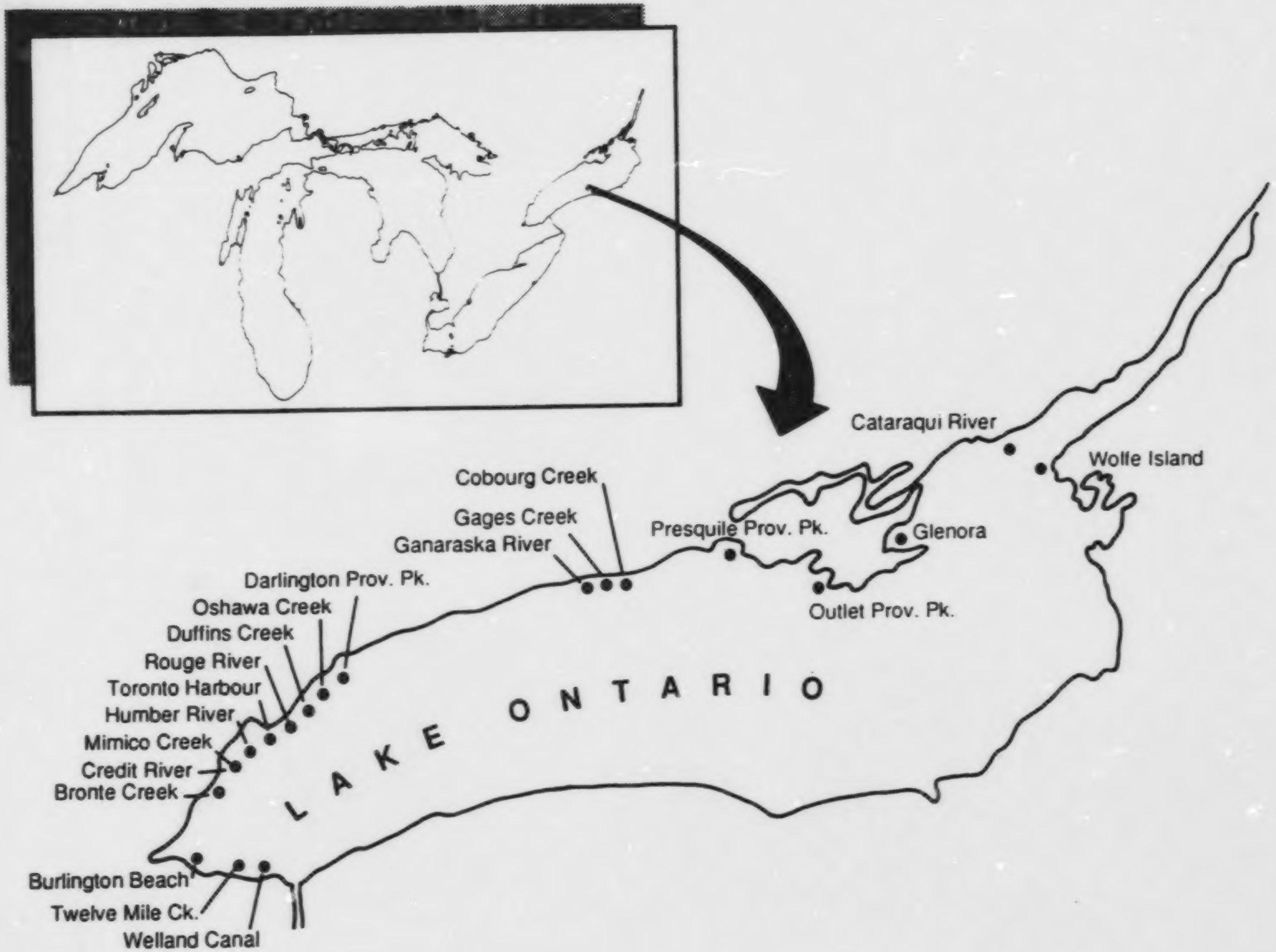
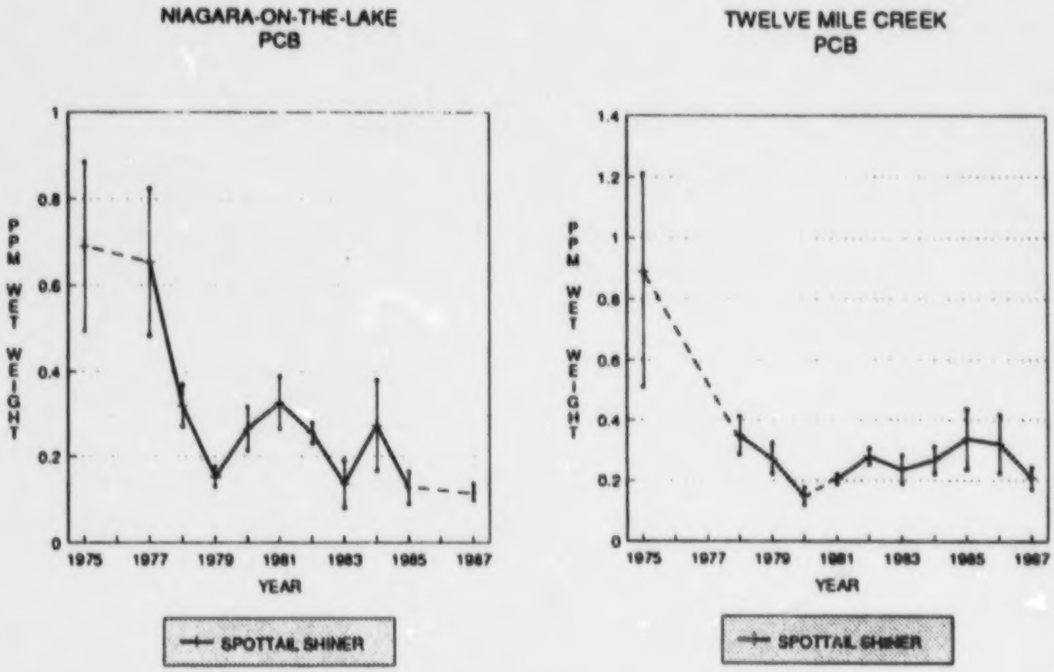

Cataraqui River
Wolfe Island
Cobourg Creek
Gages Creek
Ganaraska River
Presquile Prov. Pk.
Glenora
Outlet Prov. Pk.
Darlington Prov. Pk.
Oshawa Creek
Duffins Creek
Rouge River
Toronto Harbour
Humber River
Mimico Creek
Credit River
Bronte Creek
LAKE ONTARIO
Burlington Beach
Twelve Mile Ck.
Welland Canal

Figure 5

Spottail shiner collection sites on Lake Ontario.

LAKE ONTARIO


NIAGARA-ON-THE-LAKE
PCB

TWELVE MILE CREEK
PCB

Figure 6

Mean concentrations of PCBs (ppm, wet weight +/- standard deviation) in young-of-the-year spottail shiners from four sites on Lake Ontario.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: K. Suns, in press.

LAKE ONTARIO

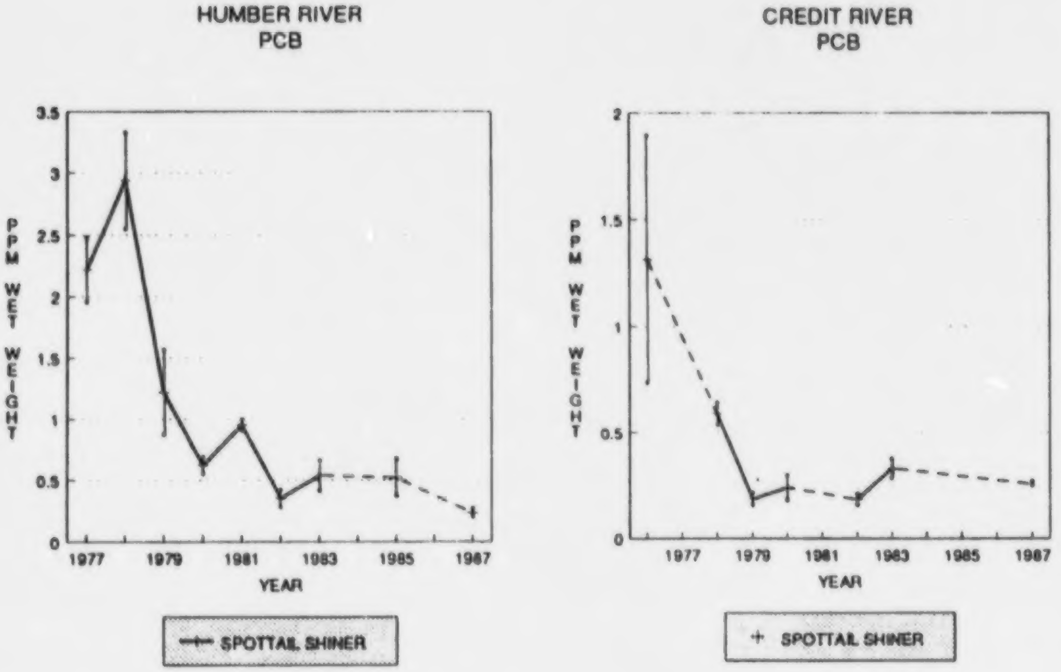


Figure 6 (continued)

LAKE ONTARIO

CREDIT RIVER
PCB

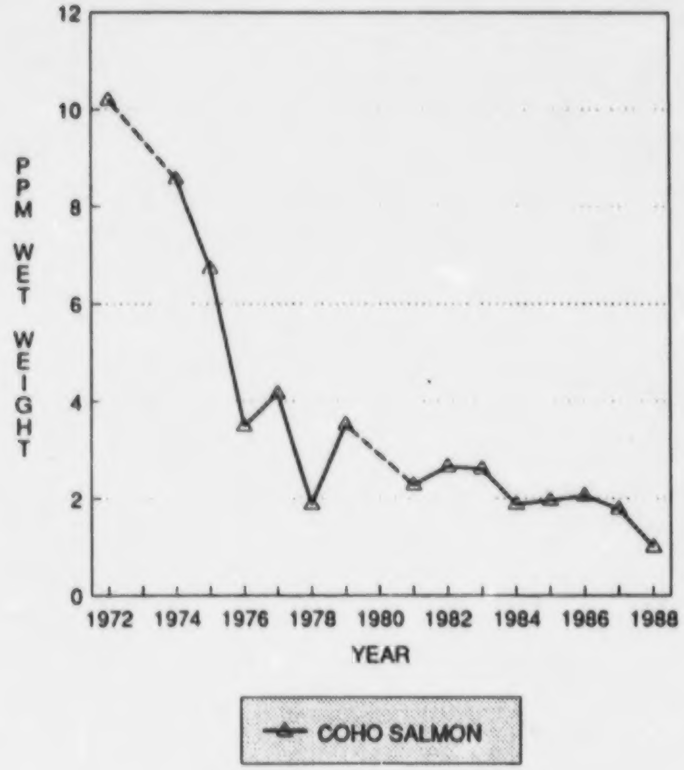


Figure 7

Concentrations of total PCBs in lean dorsal muscle tissue of coho salmon from the Credit River, Lake Ontario.

Source: Ontario Ministry of Natural Resources & Ontario Ministry of Environment (unpublished data)

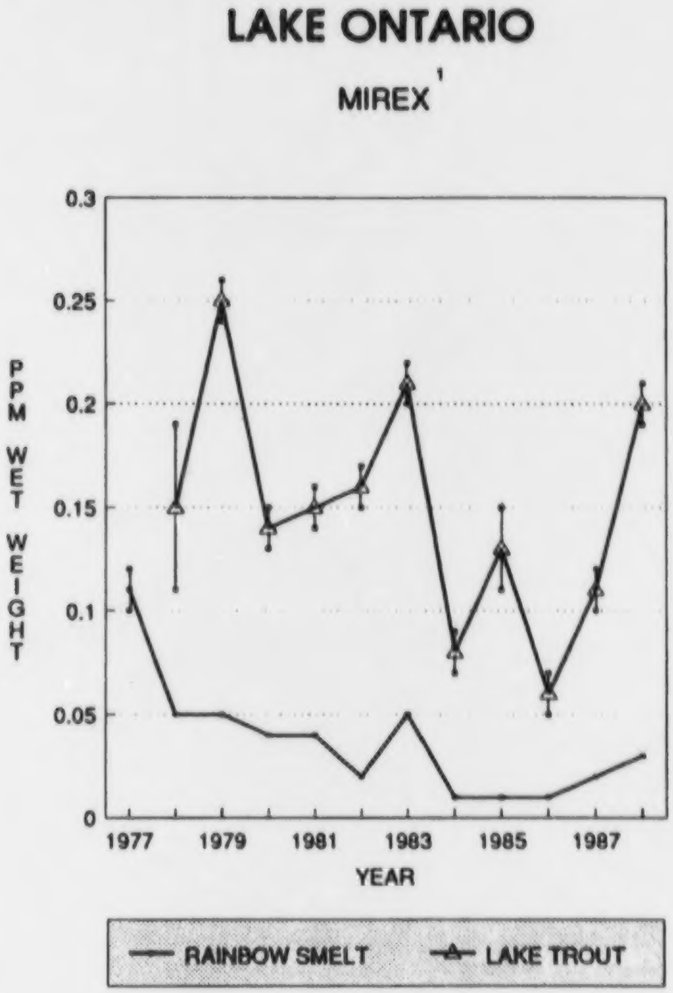
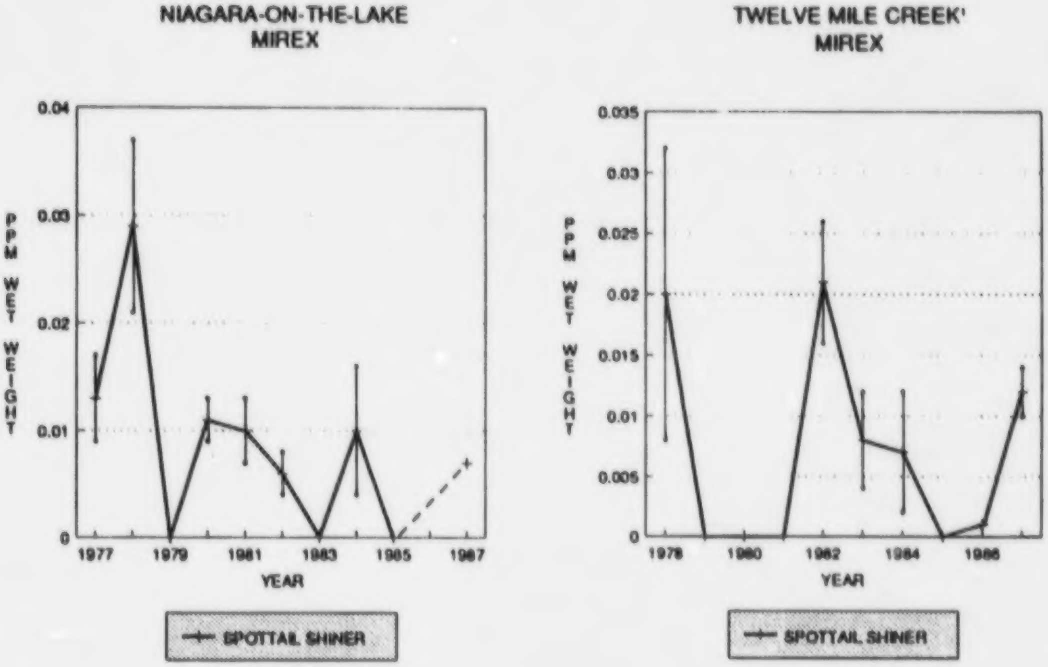


Figure 8

Mean concentrations of mirex (ppm, wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Ontario.

1. GLWQA objective for mirex is "substantially absent" (less than detection levels)
Source: Department of Fisheries & Oceans

LAKE ONTARIO


NIAGARA-ON-THE-LAKE
MIREX

TWELVE MILE CREEK¹
MIREX

Figure 9

Mean concentrations of mirex (ppm wet weight +/- standard deviation) in young-of-the year spottail shiners from two sites on Lake Ontario.

1. At Twelve Mile Creek, the 1979-81 and 1985 levels are below detectable limits

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: K. Suns, in press

LAKE ONTARIO
NIAGARA-ON-THE-LAKE
HCB

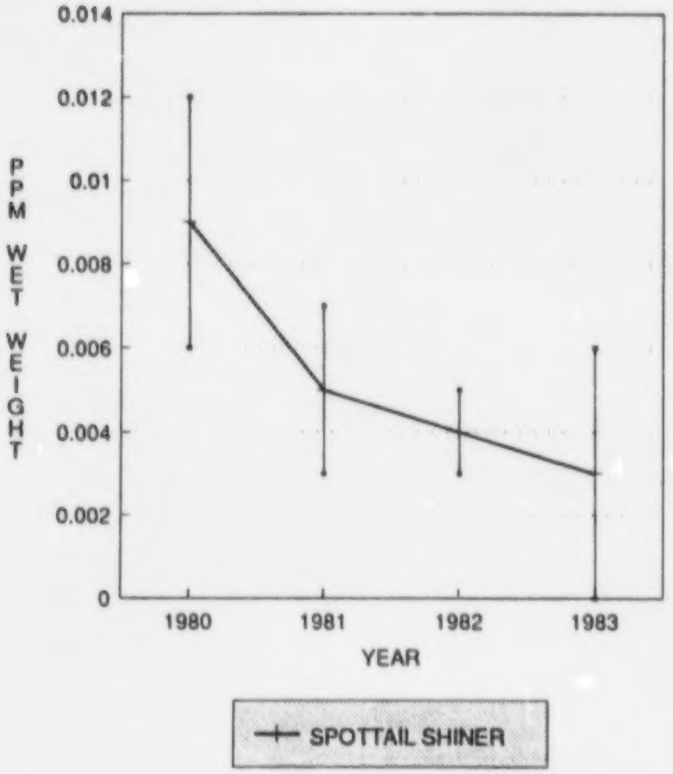


Figure 10

Mean concentrations of HCB (ppm wet weight +/- standard deviation) in young-of-the-year spottail shiners from Niagara-on-the-Lake.

Source: K. Suns, in press

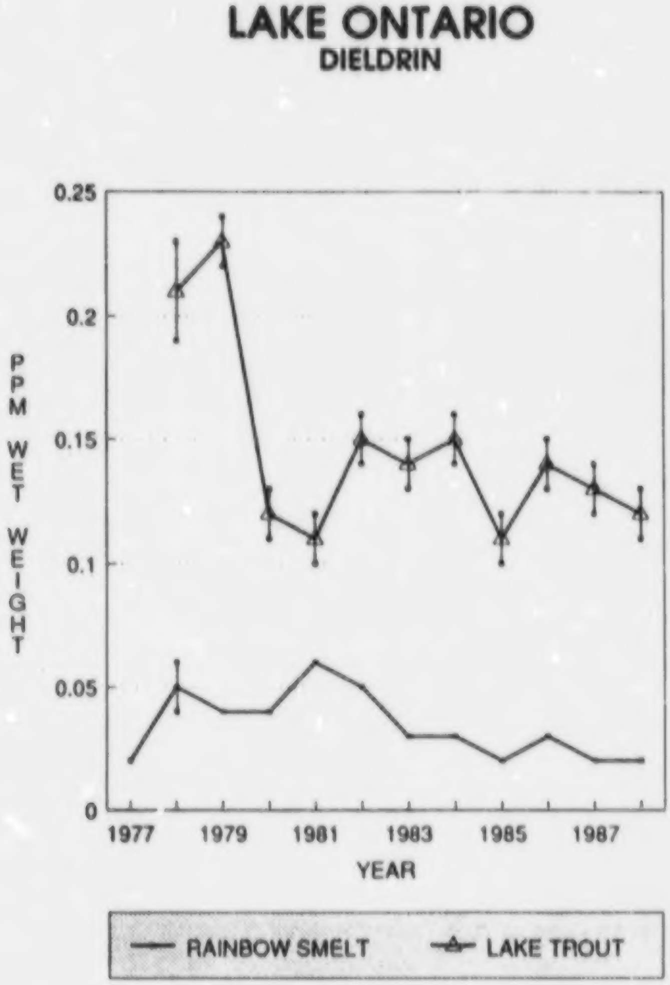


Figure 11

Mean concentrations of dieldrin (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Ontario.

Source: Department of Fisheries & Oceans

LAKE ONTARIO

DDT

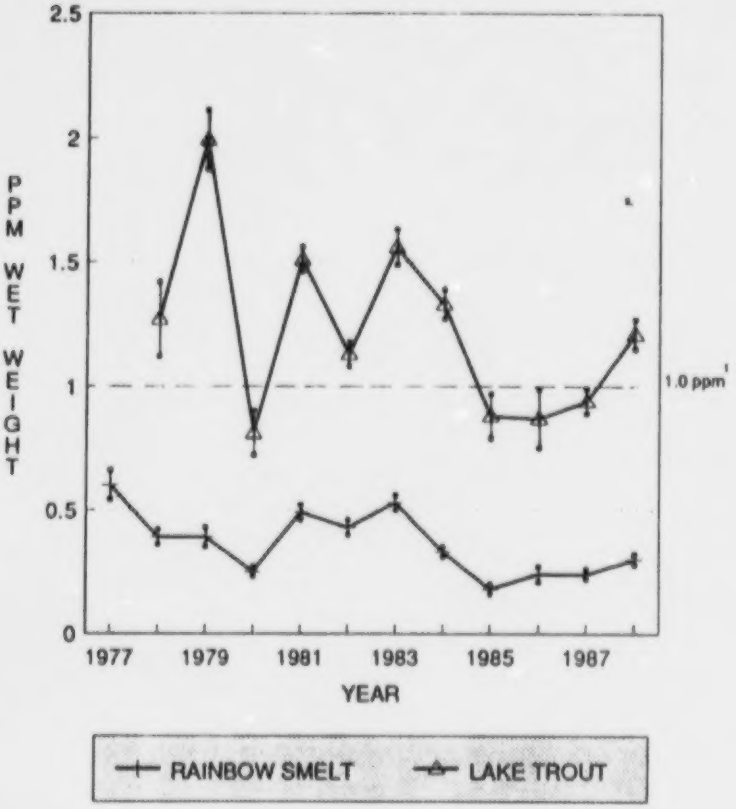


Figure 12

Mean concentrations of DDT (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout from Lake Ontario.

1. GLWQA objective for whole fish

Source: Department of Fisheries & Oceans

LAKE ONTARIO
p,p'-DDE

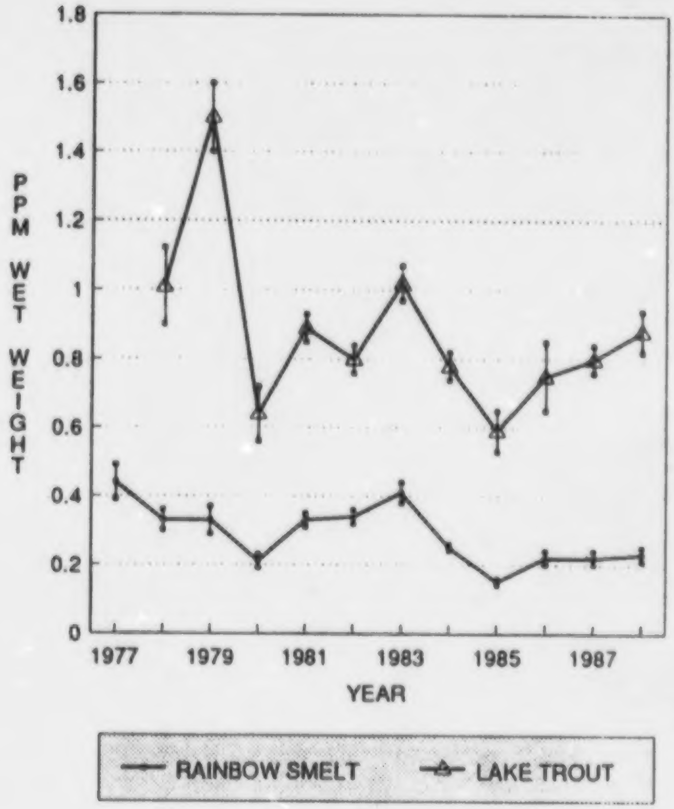


Figure 13

Mean concentrations of p,p'-DDE (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Ontario.

Source: Department of Fisheries & Oceans

LAKE ONTARIO

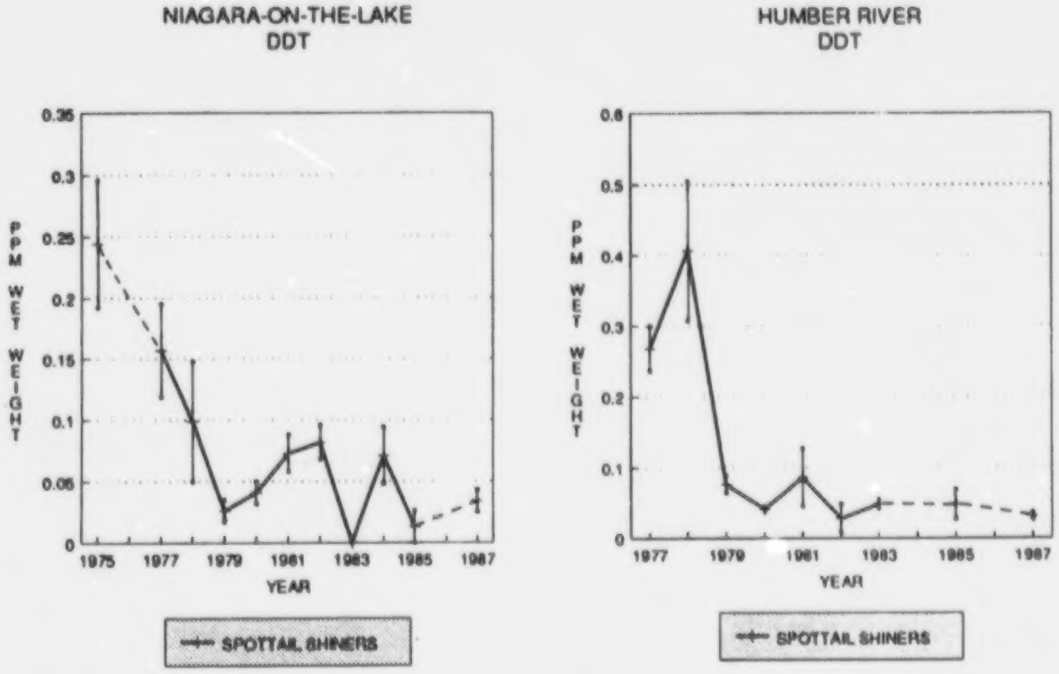


Figure 14

Mean concentrations of DDT (ppm wet weight +/- standard deviation) in young-of-the-year spottail shiners from three sites on Lake Ontario.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: K. Suns, in press

LAKE ONTARIO
TWELVE MILE CREEK
DDT

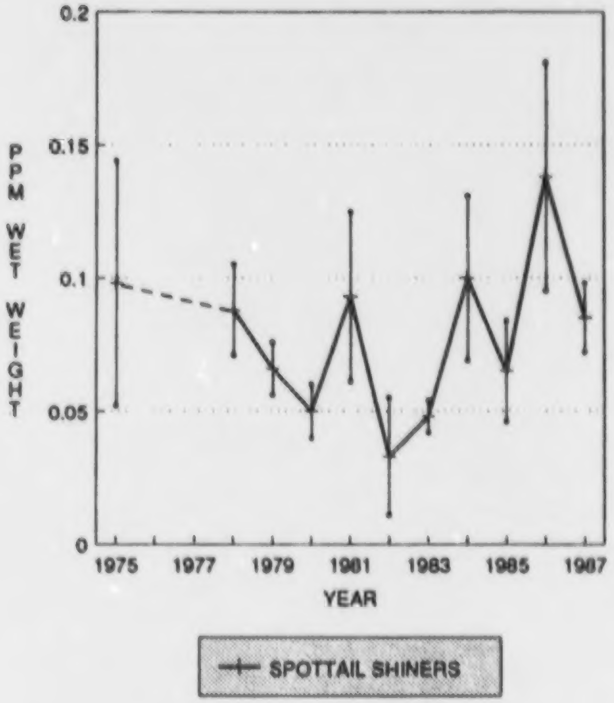


Figure 14 (continued)

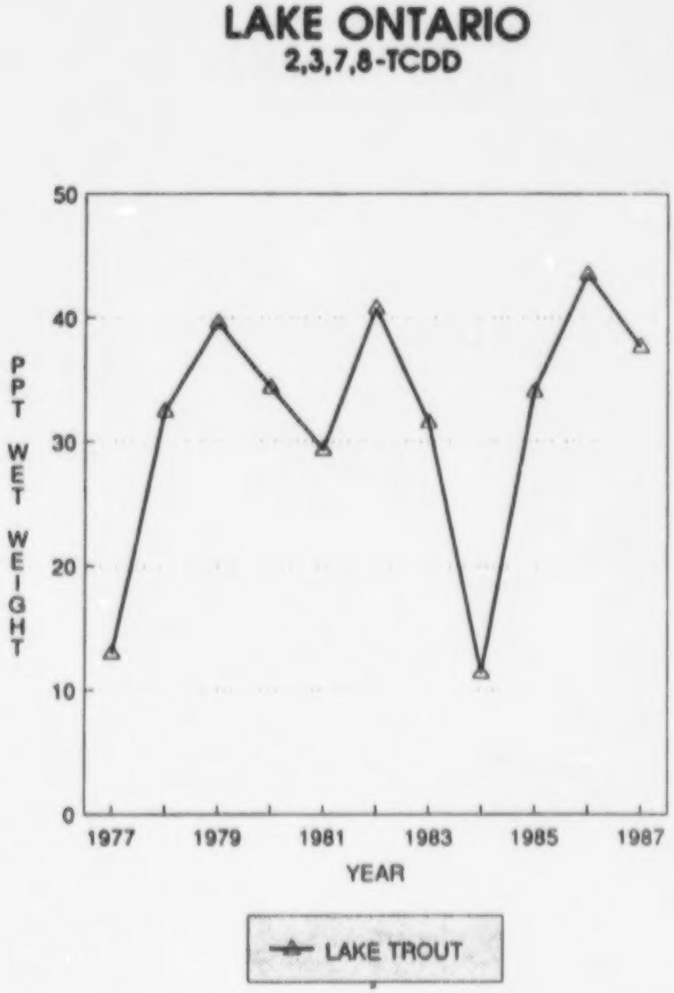
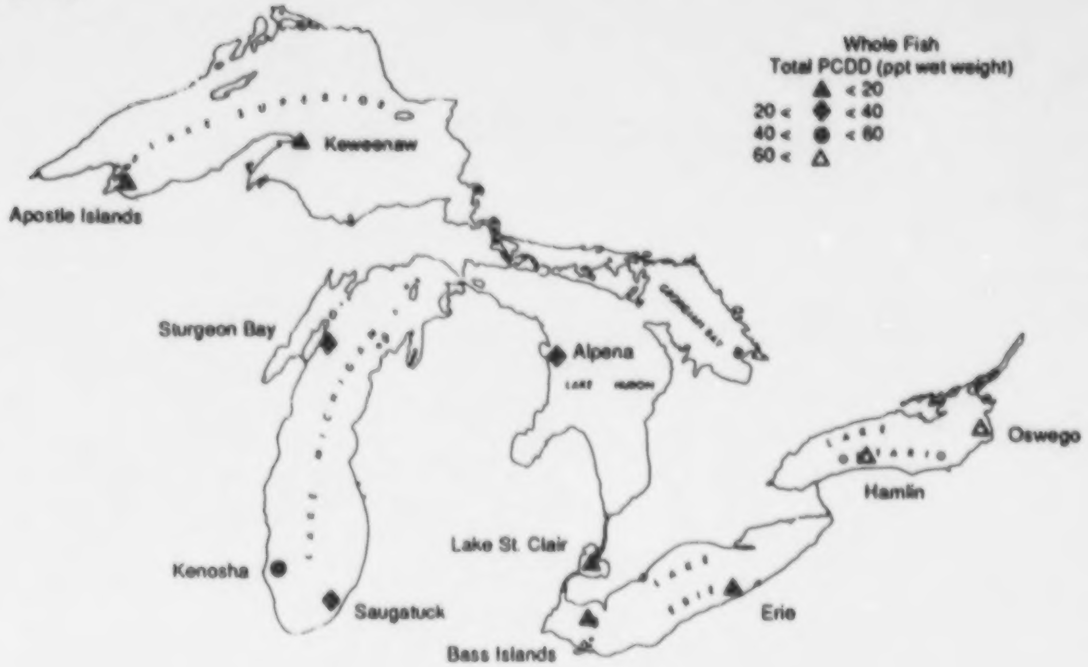


Figure 15

Mean concentrations of 2, 3, 7, 8-TCDD (ppt wet weight) in whole lake trout (age 4) from Lake Ontario.

Source: Department of Fisheries & Oceans

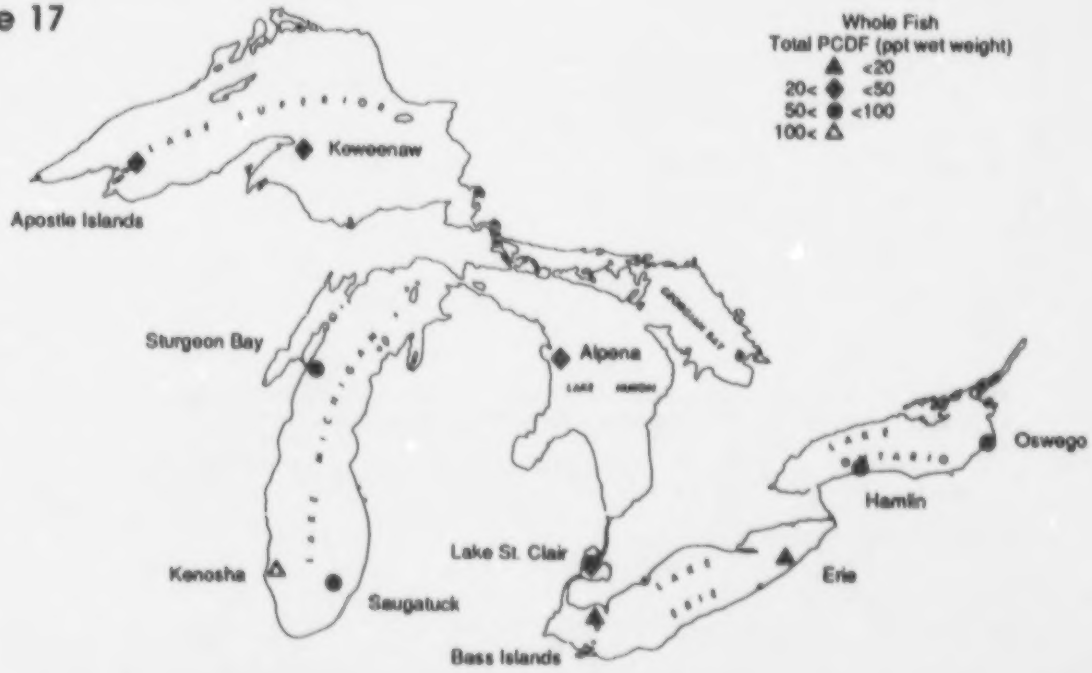
Figure 16


Whole Fish
Total PCDD (ppt wet weight)
▲ < 20
20 < ◆ < 40
40 < ● < 60
60 < △
LAKE SUPERIOR
Keweenaw
Apostle Islands
GEORGIAN BAY
Sturgeon Bay
Alpena
LAKE HURON
LAKE MICHIGAN
LAKE ONTARIO
Oswego
Hamlin
Lake St. Clair
Kenosha
Saugatuck
LAKE ERIE
Erie
Bass Islands

Spatial distribution of total polychlorinated dibenzo-p-dioxins in fish.

Note: The 2,3,7,8- congener contributed 76% of the total PCDD in Lake Ontario fish; it is relatively less important in Lake St. Clair (36%) and Lake Huron (32%) and contributes less than 20% in Lakes Superior, Michigan and Erie fish.
Source: F.C. Baumann and D.M. Whittle, 1988

Figure 17


Whole Fish
Total PCDF (ppt wet weight)
▲ <20
20< ◆ <50
50< ● <100
100< △
LAKE SUPERIOR
Keweenaw
Apostle Islands
GEORGIAN BAY
Sturgeon Bay
Alpena
LAKE HURON
LAKE MICHIGAN
LAKE ONTARIO
Oswego
Hamlin
Lake St. Clair
Kenosha
Saugatuck
LAKE ERIE
Erie
Bass Islands

Spatial distribution of total polychlorinated dibenzofurans in fish.

Note: The 2,3,7,8-TCDF congener dominates the PCDD concentrations in fish from Lakes Superior, Huron, Michigan, St. Clair and Erie. The Lake Ontario samples were dominated by 2,3,4,7,8-PeCDF followed by 2,3,7,8-TCDF.
Source: F.C. Baumann and D.M. Whittle, 1988

LAKE ONTARIO

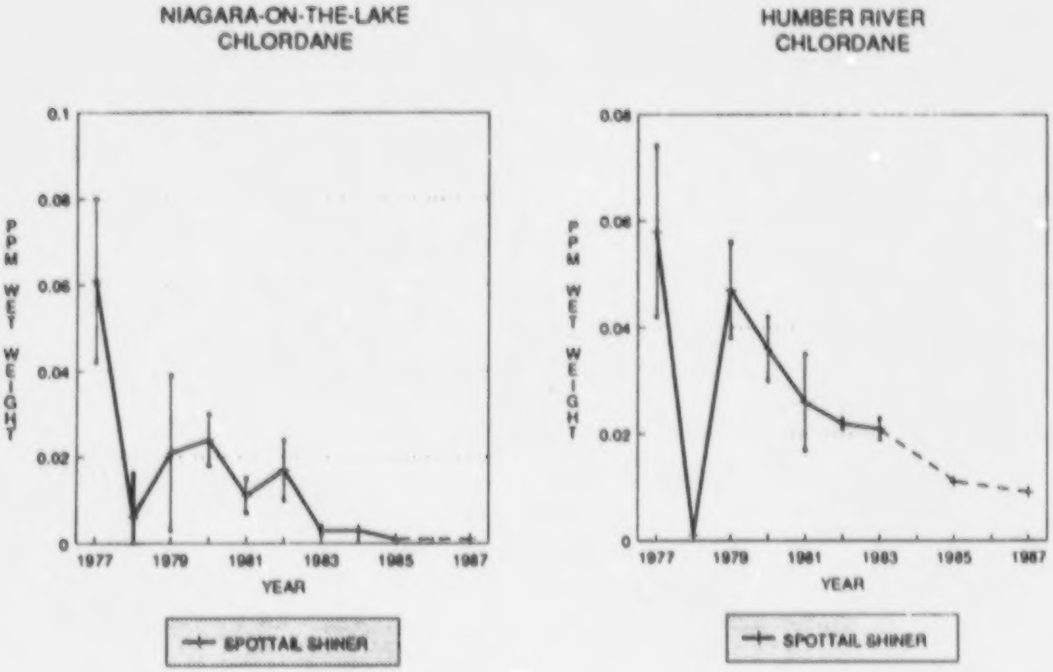


Figure 18

Mean concentrations of chlordane (ppm wet weight +/- standard deviation) in young-of-the-year spottail shiners from two sites on Lake Ontario.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: K. Suns, in press

LAKE ONTARIO

MERCURY[1]

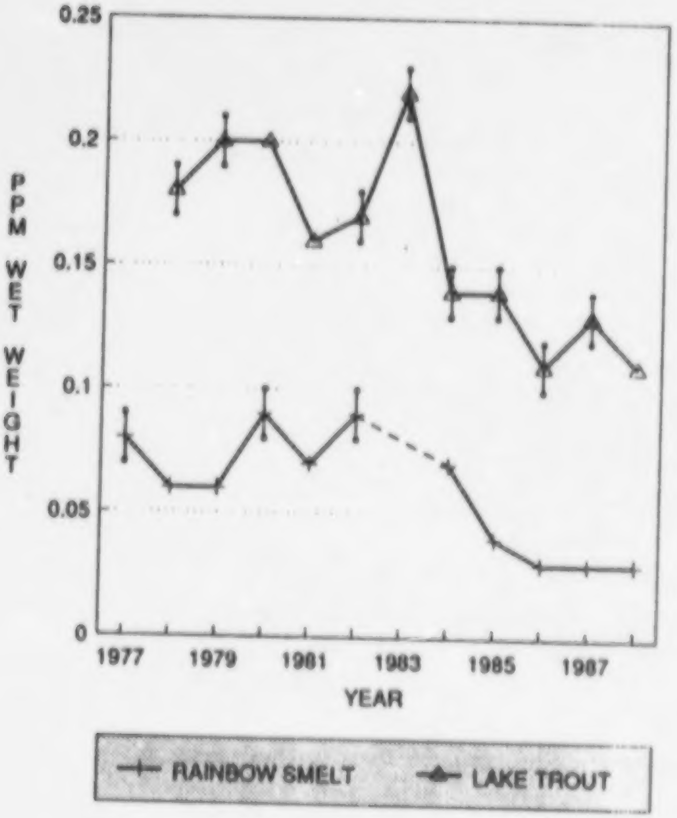


Figure 19

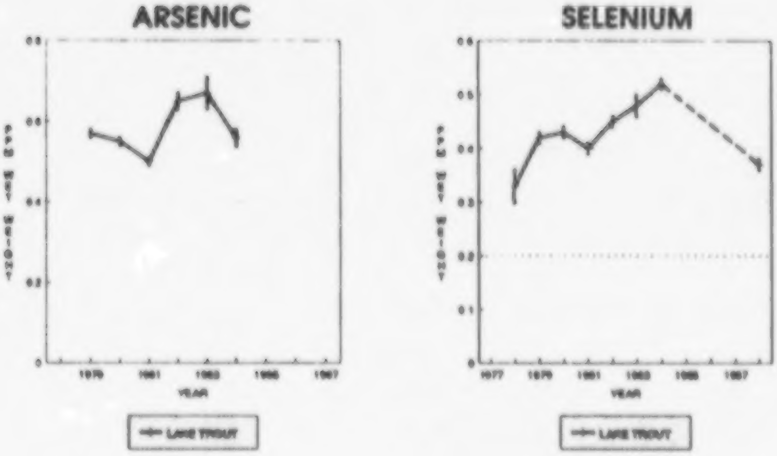
Mean concentrations of mercury (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Ontario.

1. GLWQA objective concentration of total mercury for whole fish is 0.5 ppm (wet weight basis).

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans

LAKE ONTARIO



Figures 20 and 21

Mean concentrations of arsenic and selenium (ppm wet weight +/- standard error) in whole lake trout from Lake Ontario.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.
Source: Department of Fisheries and Oceans.

LAKE ONTARIO

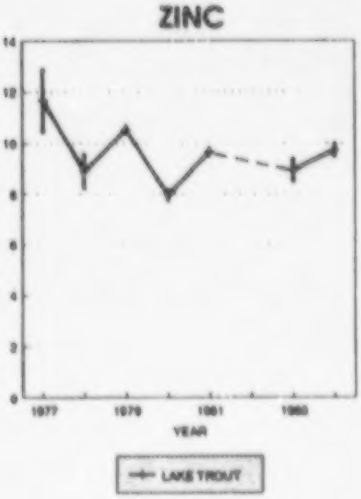


Figure 22

Mean concentrations of zinc (ppm wet weight +/- standard error) in whole lake trout from Lake Ontario.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries and Oceans

LAKE ERIE
PCB

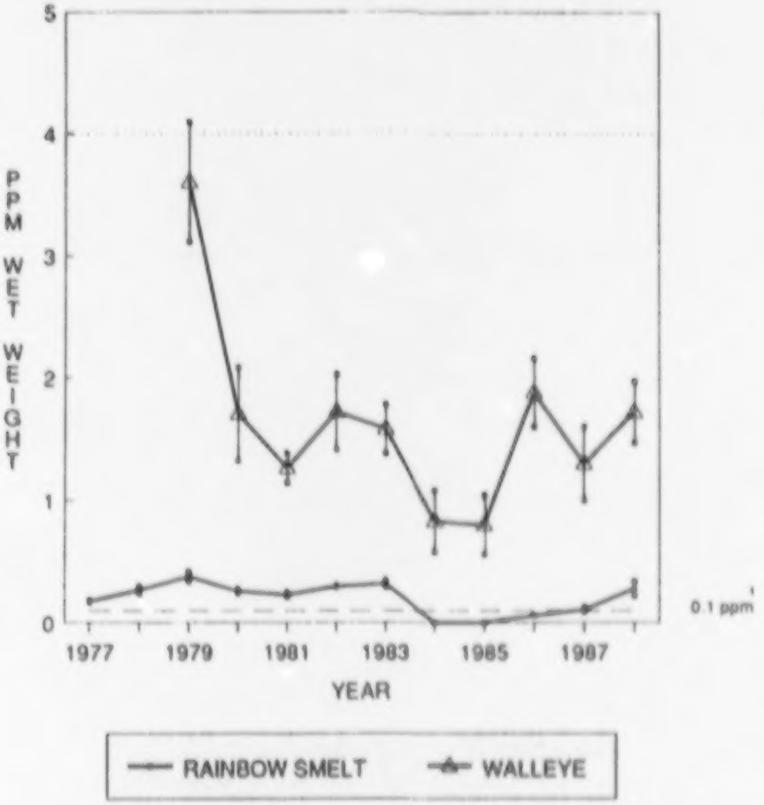


Figure 23

Mean concentrations of PCBs (ppm wet weight +/- standard error) in whole rainbow smelt and walleye from Lake Erie.

1. GLWQA objective for whole fish.

Note: 1984 & 1985 levels for rainbow smelt are below detection limit (0.1 ppm).

Source: Department of Fisheries & Oceans

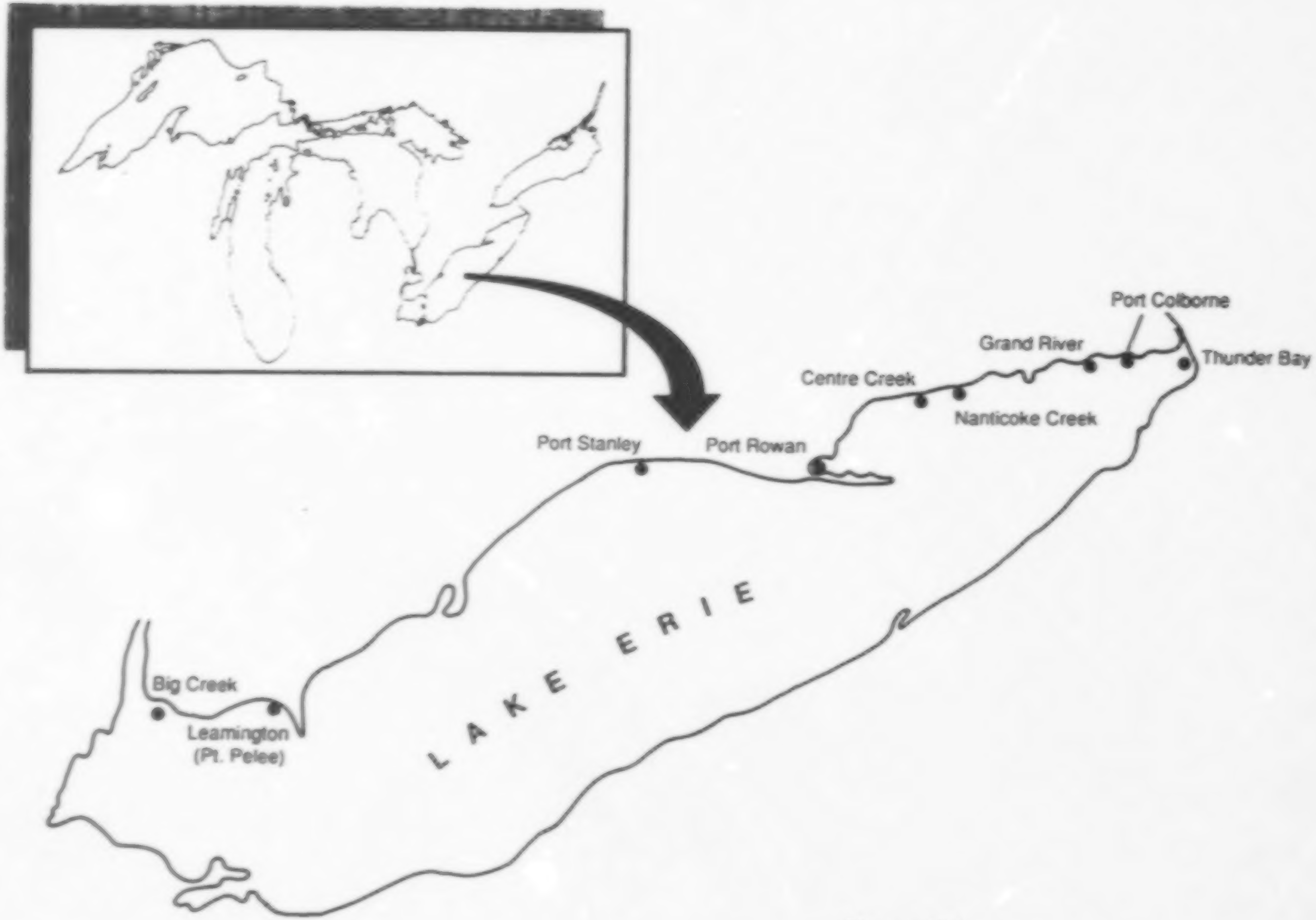

Port Colborne
Grand River
Thunder Bay
Centre Creek
Nanticoke Creek
Port Stanley
Port Rowan
LAKE ERIE
Big Creek
Leamington
(Pt. Pelee)

Figure 24

Spottail shiner collection sites on Lake Erie.

LAKE ERIE

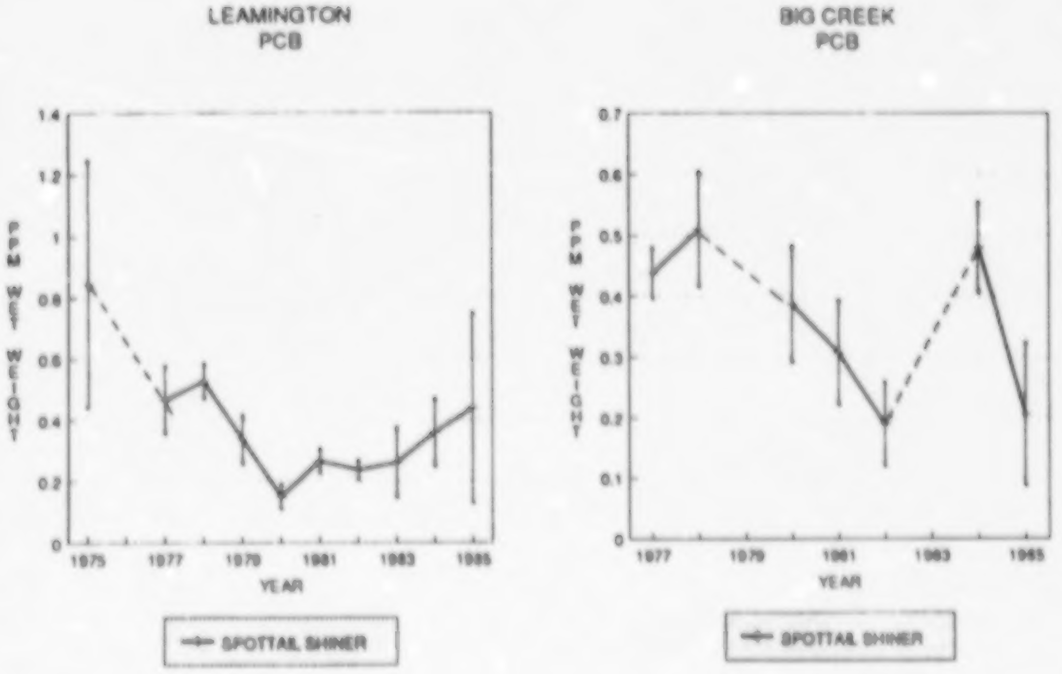


Figure 25

Mean concentrations of PCBs (ppm wet weight +/- standard deviation) in young-of-the-year spottail shiners from two sites on Lake Erie.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: K. Suns, Ontario Ministry of the Environment

LAKE ERIE
DIELDRIN

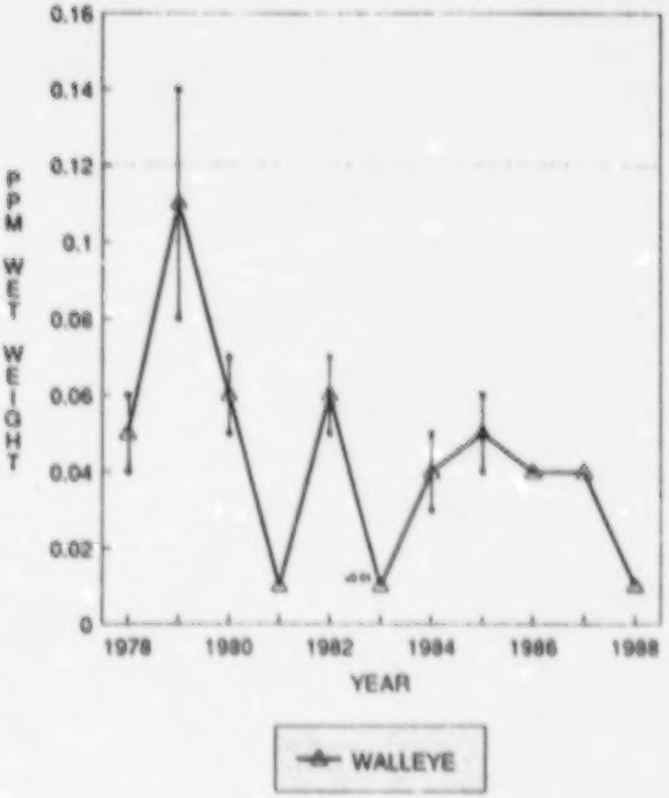


Figure 26

Mean concentrations of dieldrin (ppm wet weight +/- standard error) in whole walleye from Lake Erie.

Source: Department of Fisheries and Oceans.

LAKE ERIE
DDT

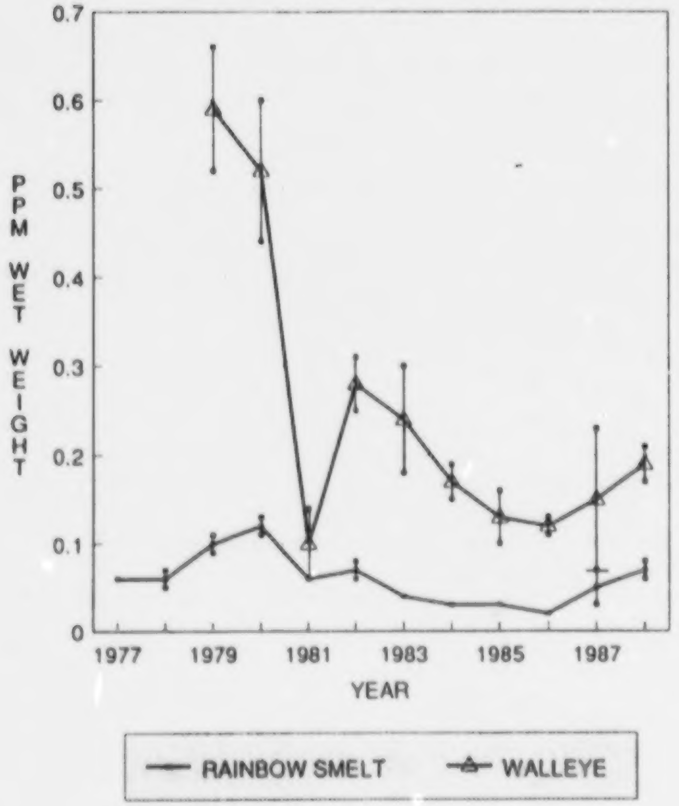
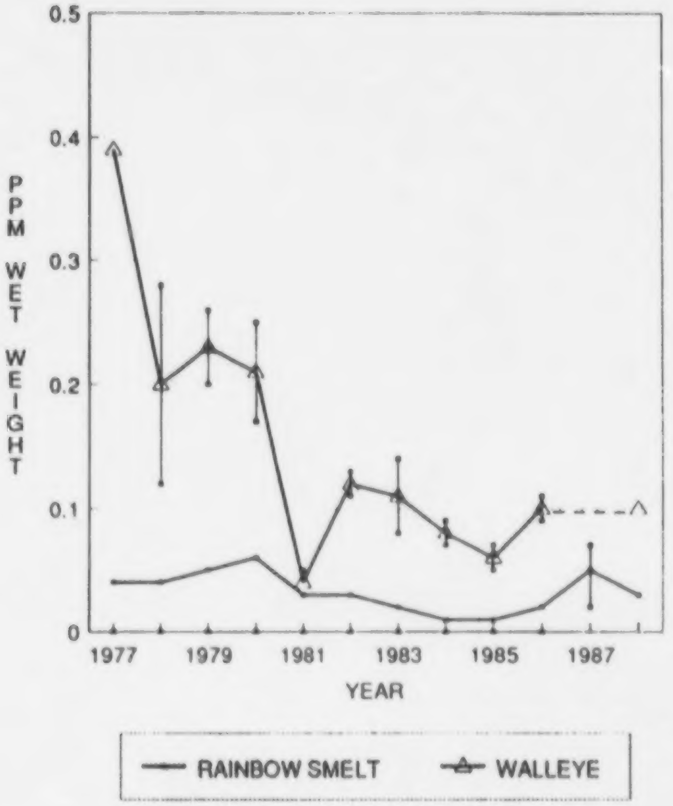


Figure 27

Mean concentrations of DDT (ppm wet weight +/- standard error) in whole rainbow smelt and walleye from Lake Erie.

Source: Department of Fisheries and Oceans.



LAKE ERIE
p,p'-DDE

Figure 28

Mean concentrations of p,p'-DDE (ppm wet weight +/- standard error) in whole rainbow smelt and walleye from Lake Erie.

Note: Where data are not available in consecutive years, dotted lines are used to lestimat the trend.

Source: Department of Fisheries & Oceans

LAKE ERIE

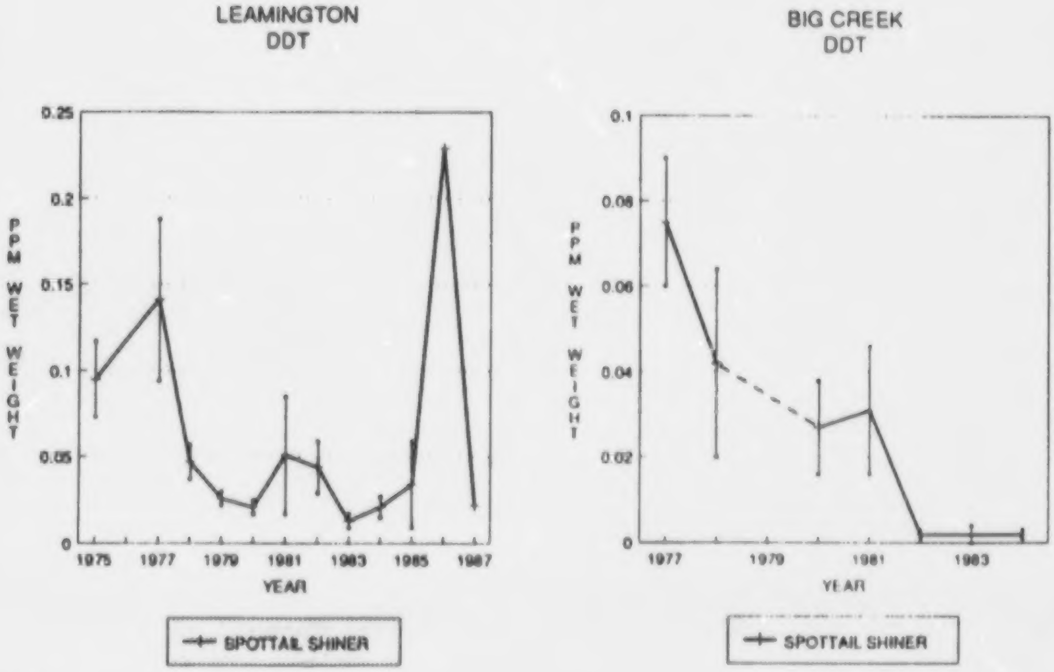


Figure 29

Mean concentrations of DDT (ppm wet weight +/- standard deviation) in young-of-the-year spottail shiners from two sites on Lake Erie.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: K. Suns, Ontario Ministry of the Environment

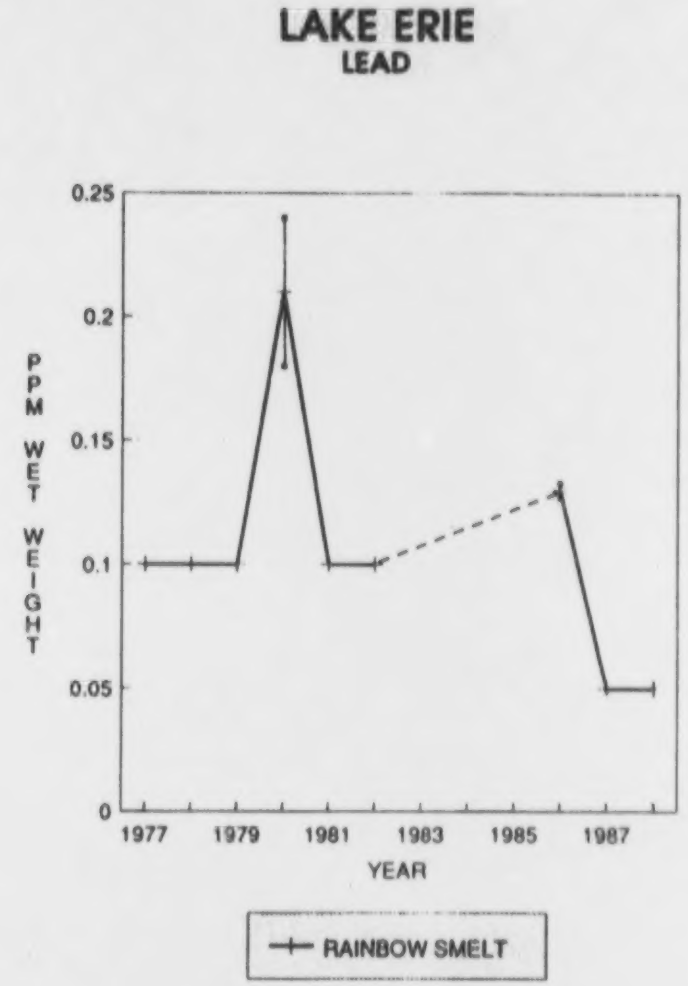


Figure 30

Mean concentrations of lead (ppm wet weight +/- standard error) in whole rainbow smelt from Lake Erie.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans.

LAKE ERIE
MERCURY

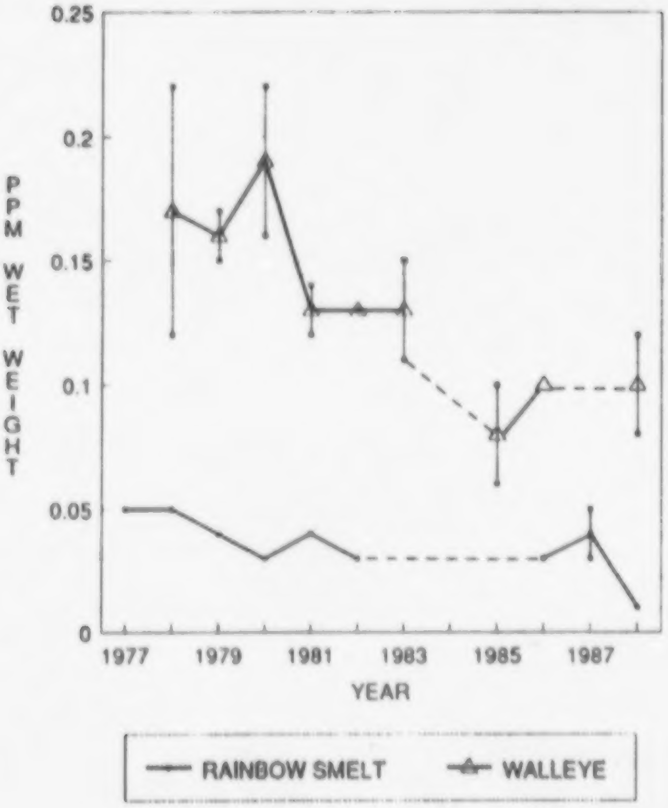


Figure 31

Mean concentrations of mercury (ppm wet weight +/- standard error) in whole rainbow smelt and walleye from Lake Erie.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries and Oceans

LAKE HURON
PCB

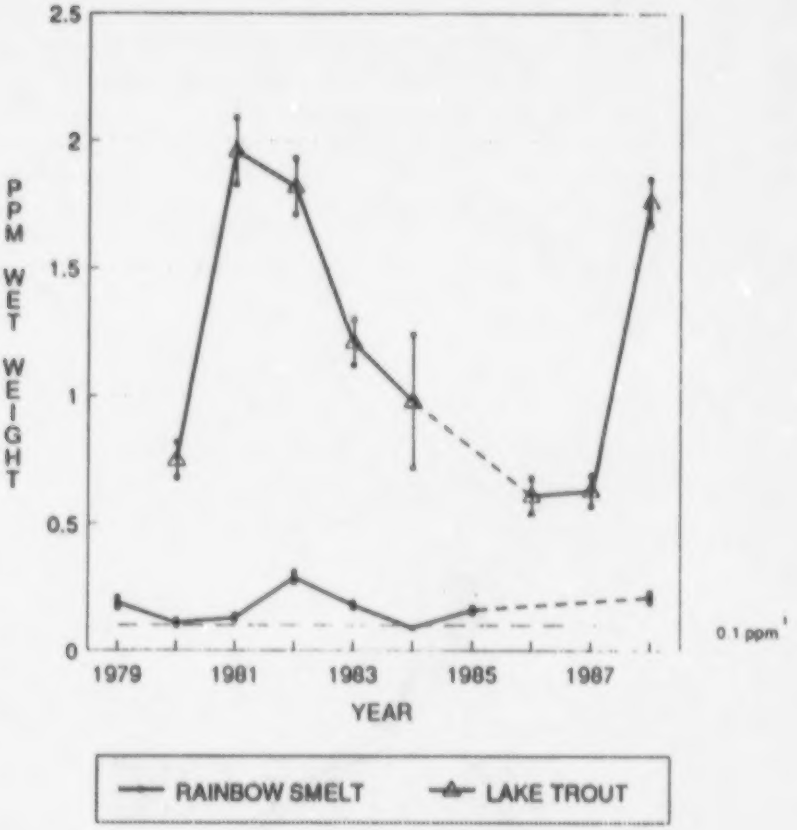


Figure 32

Mean concentrations of PCBs in whole rainbow smelt and lake trout (age 4) from Lake Huron.

1. Great Lakes Water Quality Agreement Objective for whole fish.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans

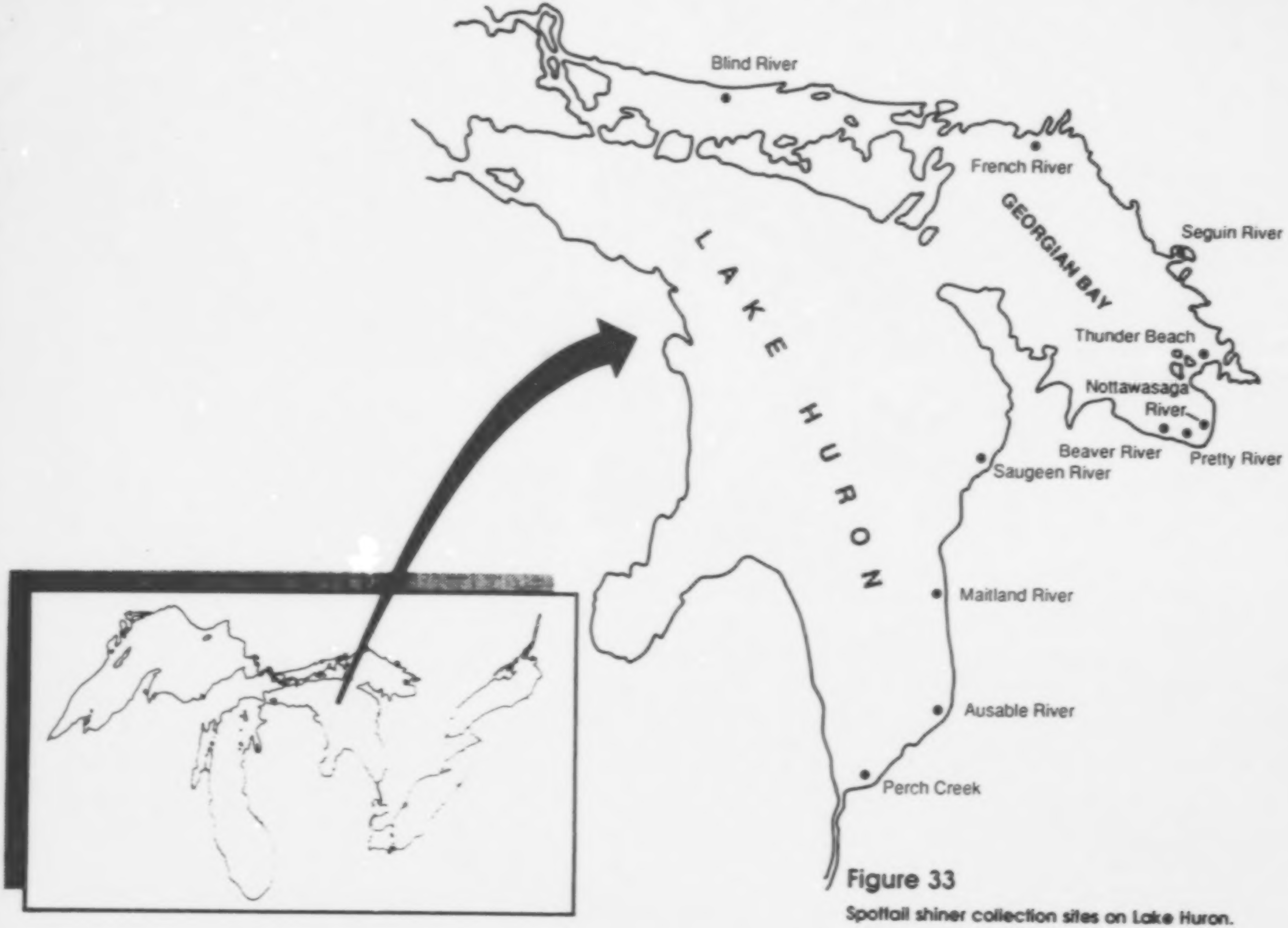

Blind River
French River
GEORGIAN BAY
Seguin River
Thunder Beach
Nottawasaga River
Beaver River
Pretty River
Saugeen River
LAKE HURON
Maitland River
Ausable River
Perch Creek

Figure 33

Spottail shiner collection sites on Lake Huron.

LAKE HURON
DIELDRIN

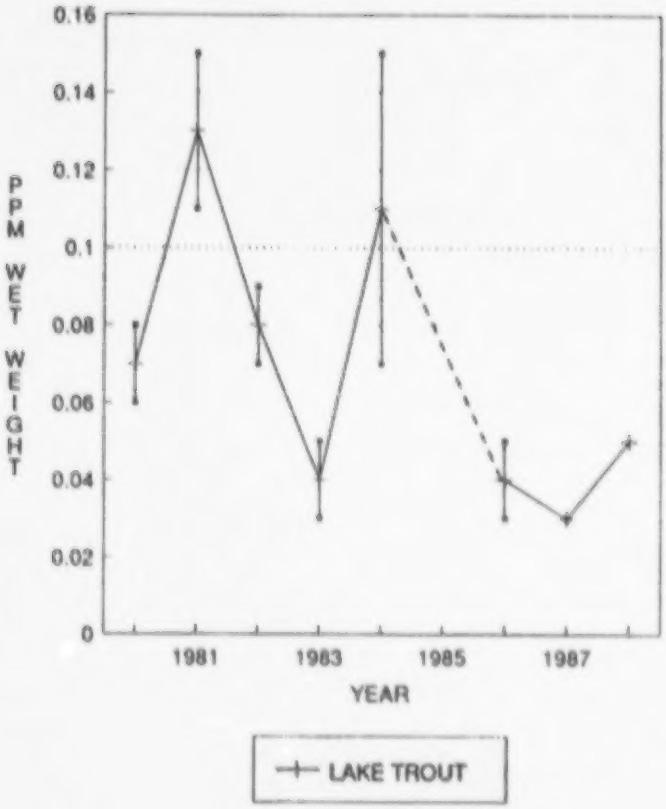


Figure 34

Mean concentrations of dieldrin (ppm wet weight +/- standard error) in whole lake trout (age 4) from Lake Huron. Concentration for rainbow smelt was below detection limit (<0.01 ppm).

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans

LAKE HURON
DDT

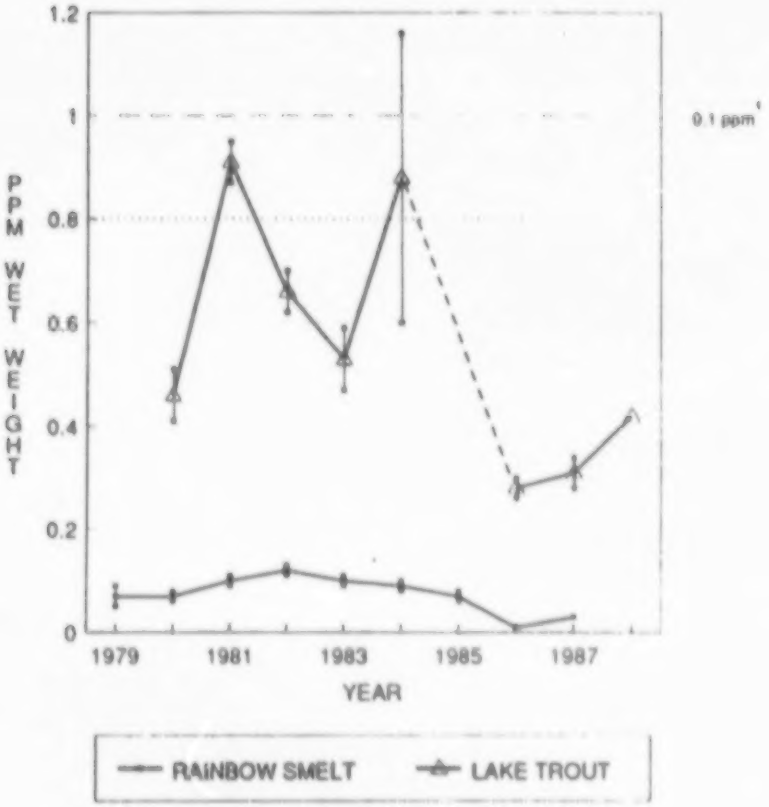


Figure 35

Mean concentrations of DDT (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Huron.

1. GLWQA Objective for Whole Fish.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans

LAKE HURON
p,p'-DDE

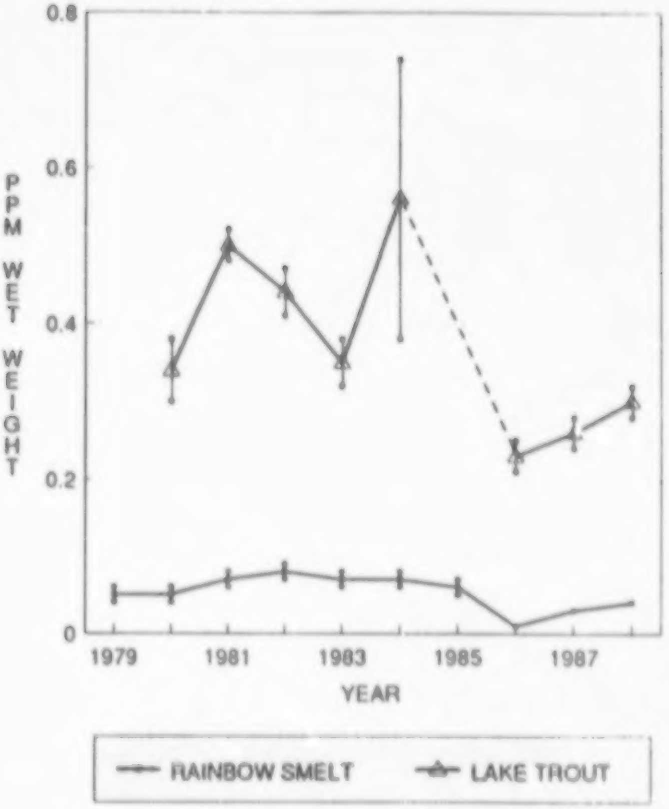


Figure 36

Mean concentrations of p,p'-DDE (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Huron.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries and Oceans

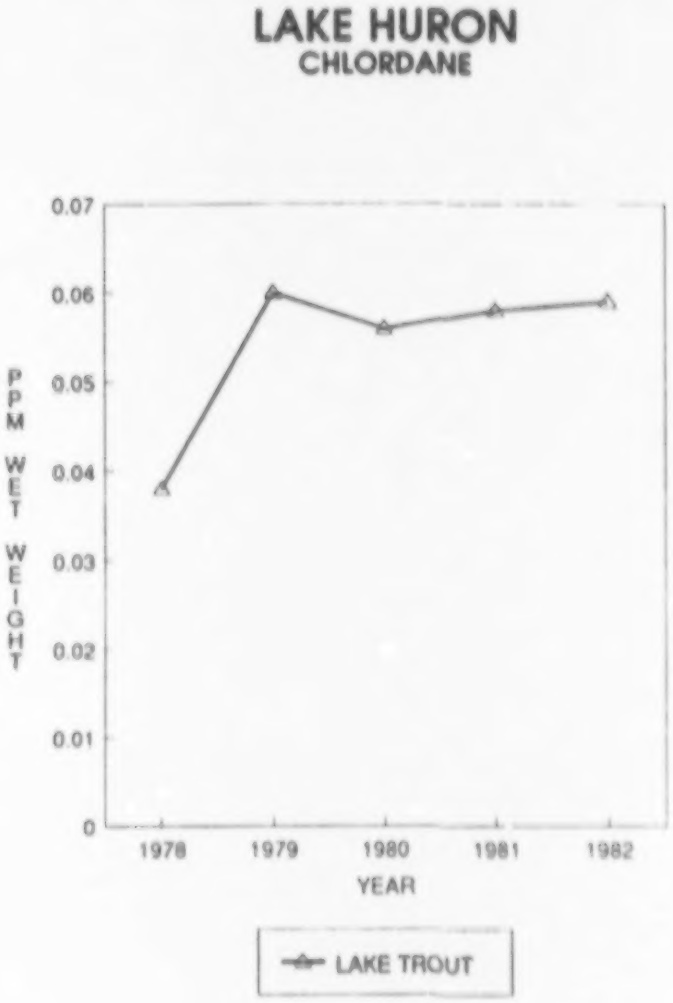


Figure 37

Mean concentrations of chlordane (ppm wet weight) (no standard error available) in lake trout (age 4) from Lake Huron.

Source: Department of Fisheries and Oceans

LAKE HURON
MERCURY

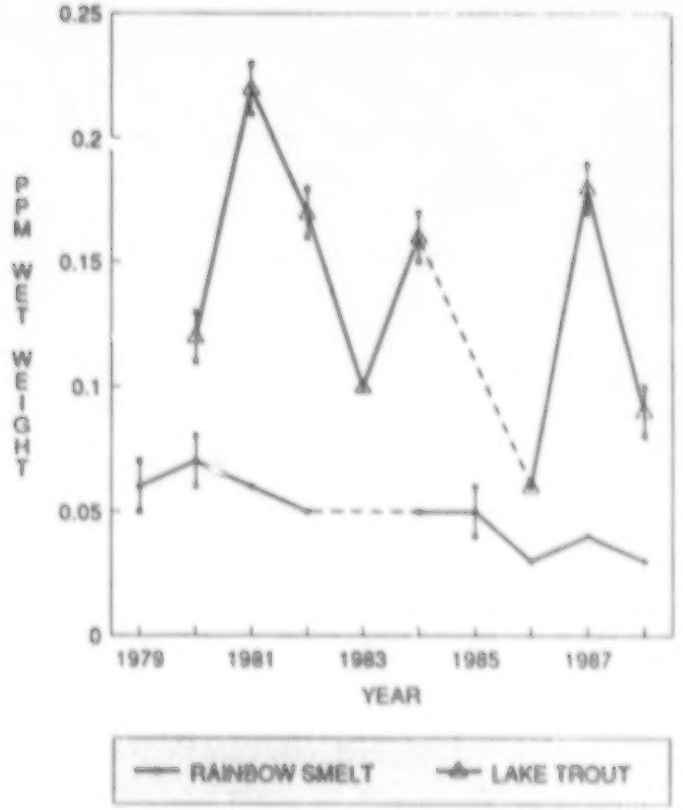


Figure 38

Mean concentrations of mercury (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Huron.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans

LAKE SUPERIOR

PCB

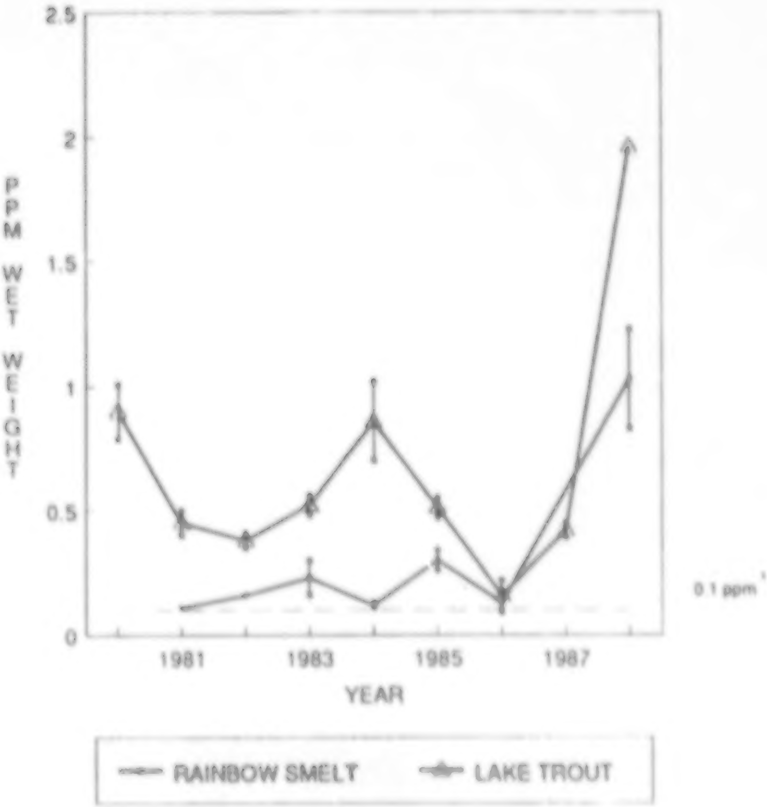


Figure 39

Mean concentrations of PCBs (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Superior.

1. GLWQA objective for whole fish.

Source: Department of Fisheries & Oceans

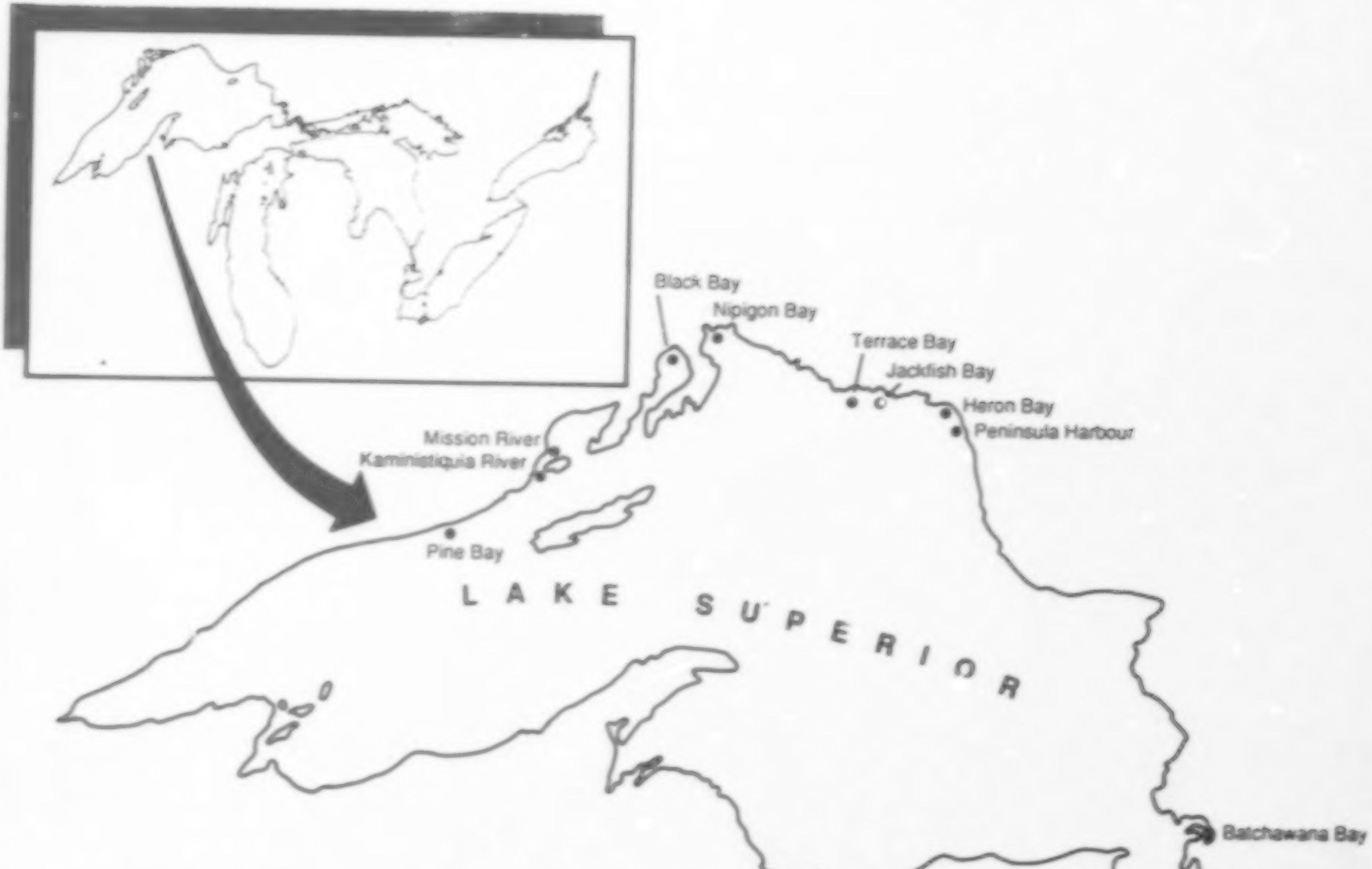

Black Bay
Nipigon Bay
Terrace Bay
Jackfish Bay
Heron Bay
Peninsula Harbour
Mission River
Kaministiquia River
Pine Bay
LAKE SUPERIOR
Batchawana Bay
Sault St. Marie
Little Lake George

Figure 40

Spottail shiner collection sites on Lake Superior.

LAKE SUPERIOR
DIELDRIN

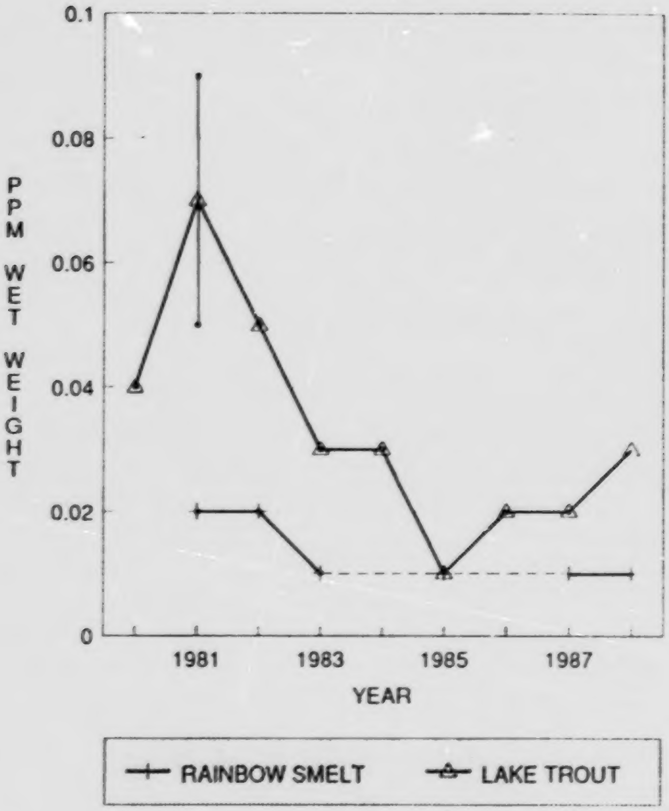


Figure 41

Mean concentrations of dieldrin (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Superior. When not indicated, standard error = 0

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries and Oceans

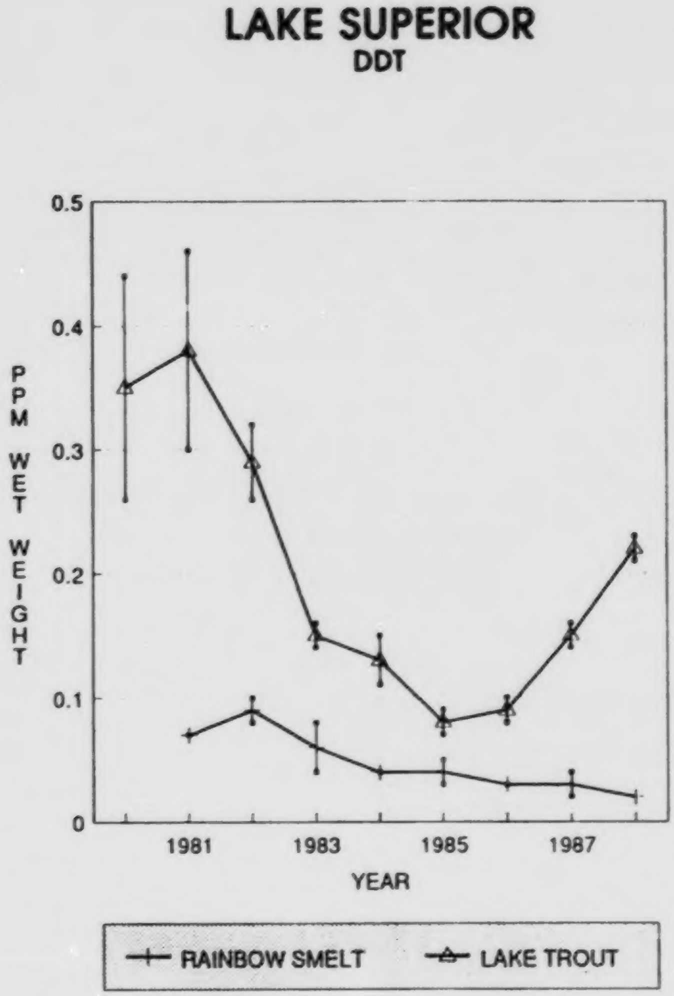
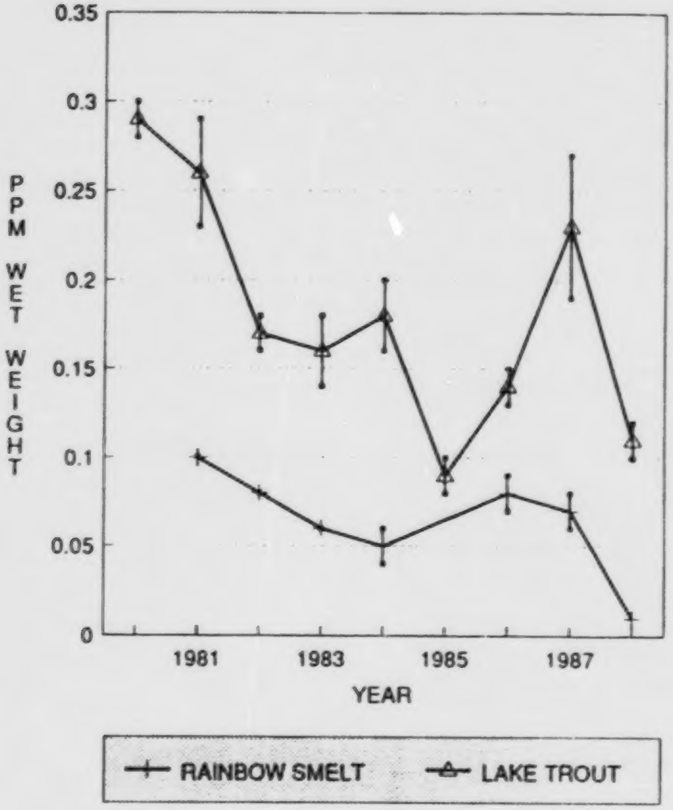


Figure 42

Mean concentrations of DDT (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Superior.

Source: Department of Fisheries & Oceans



LAKE SUPERIOR

p,p'-DDE

Figure 43

Mean concentrations of p,p'-DDE (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Superior.

Source: Department of Fisheries & Oceans

LAKE SUPERIOR
MERCURY

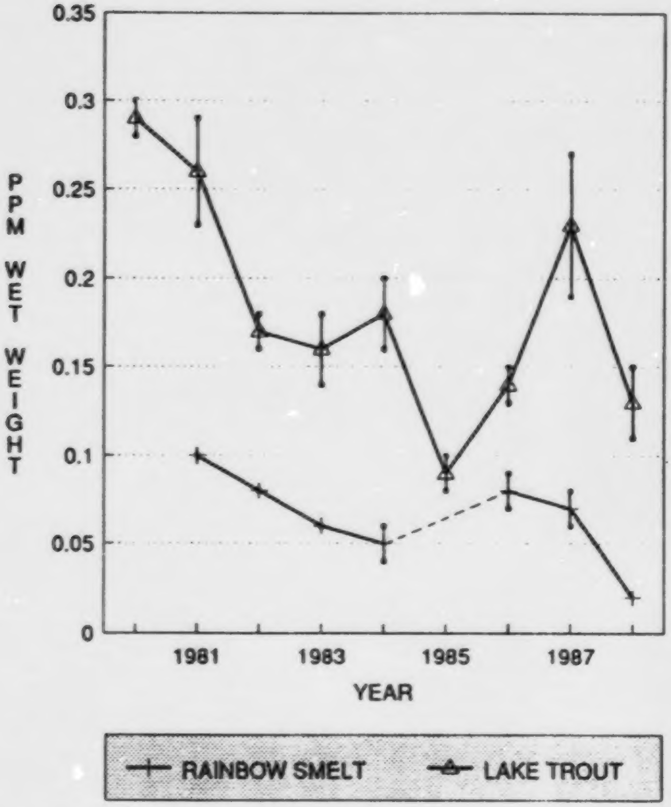


Figure 44

Mean concentrations of mercury (ppm wet weight +/- standard error) in whole rainbow smelt and lake trout (age 4) from Lake Superior.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Department of Fisheries & Oceans

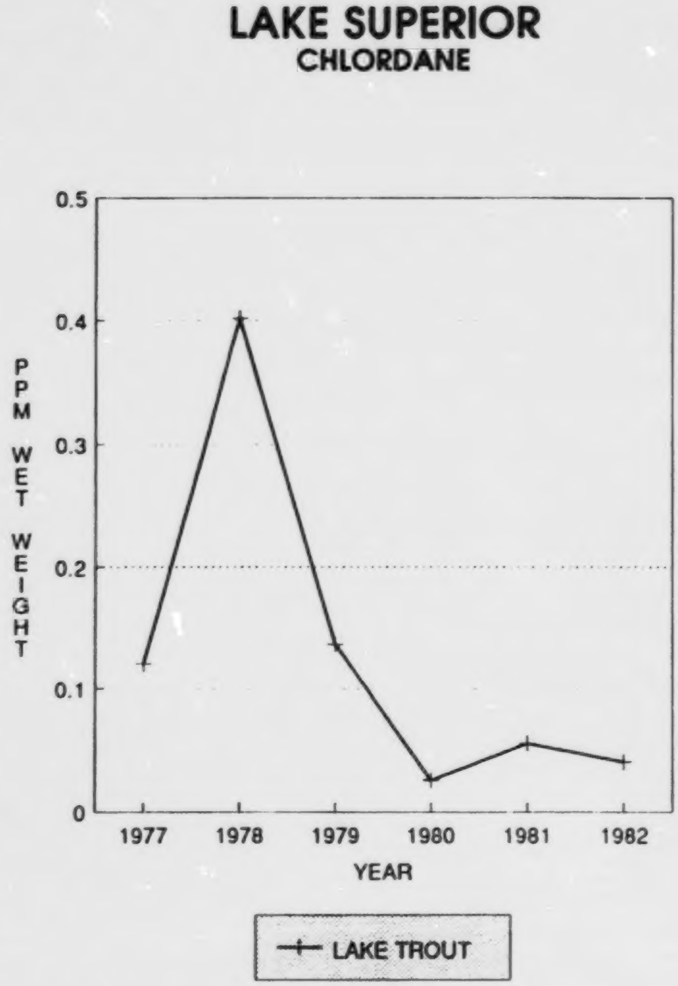


Figure 45

Mean concentrations of chlordane (ppm wet weight) (no standard error available) in whole lake trout (age 4) from Lake Superior.

Source: Department of Fisheries and Oceans

LAKE MICHIGAN
PCB

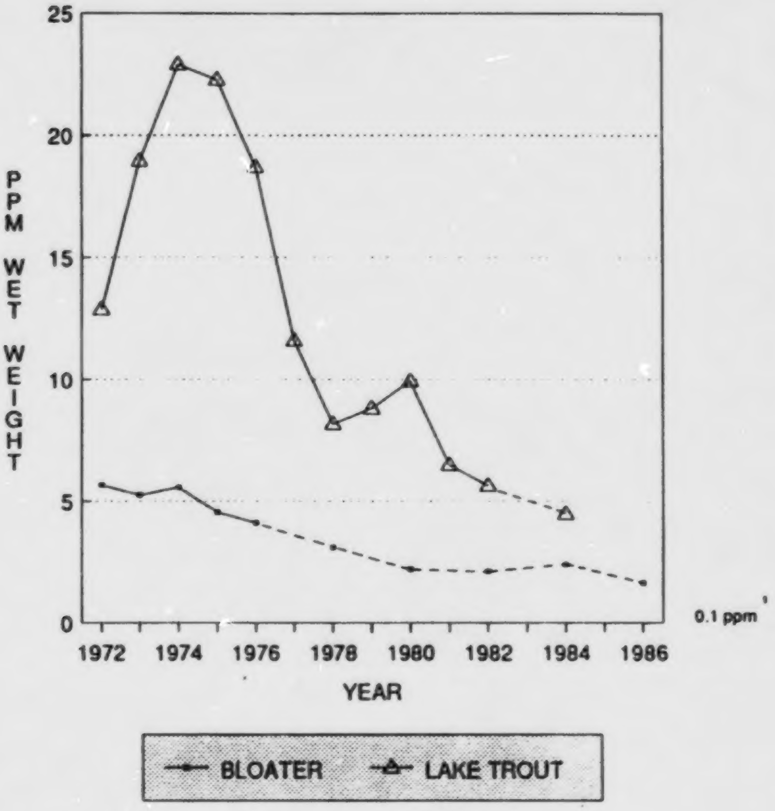


Figure 46

Mean concentrations of PCBs (ppm wet weight) in whole bloater and lake trout (620-640 mm mean length) from Lake Michigan.

1. GLWQA Objective for whole fish.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Bloater data are from U.S. Fish & Wildlife Service; lake trout data are from a cooperative program of the U.S. Fish & Wildlife Service and U.S. Environmental Protection Agency, Great Lakes National Programs Office.

LAKE MICHIGAN
DIELDRIN

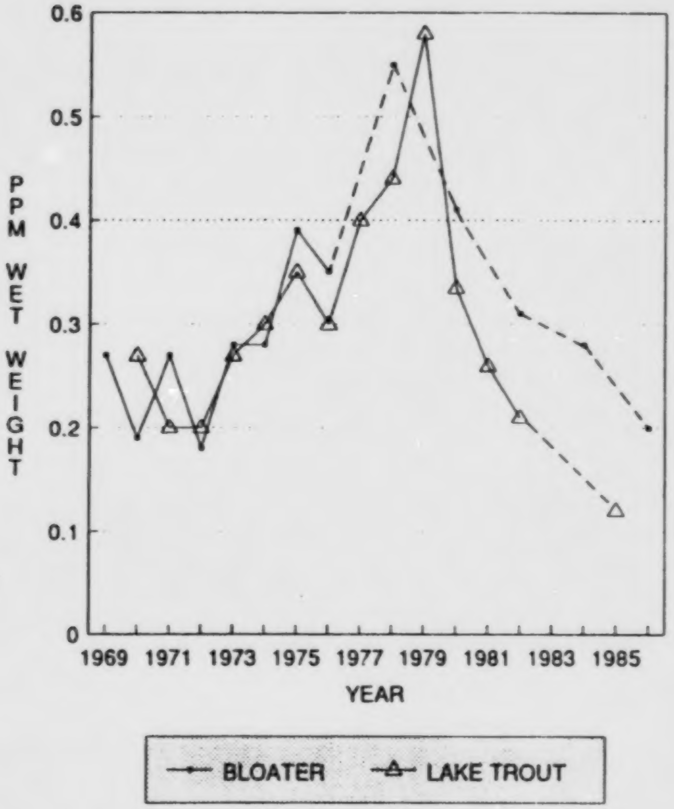


Figure 47

Mean concentrations of dieldrin (ppm wet weight) in whole bloater and lake trout (620-640 mm mean length) from Lake Michigan.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Bloater data are from U.S. Fish & Wildlife Service; lake trout data are from a cooperative program of the U.S. Fish & Wildlife Service and U.S. Environmental Protection Agency, Great Lakes National Programs Office.

LAKE MICHIGAN

DDT

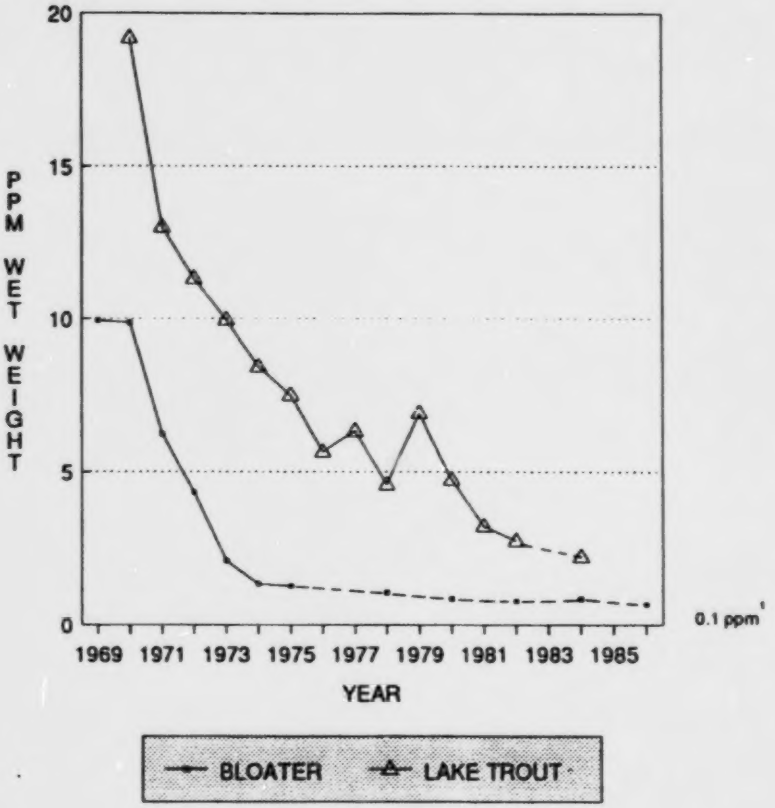


Figure 48

Mean concentrations of DDT (ppm wet weight) in whole bloater and lake trout (620-640 mm mean length) from Lake Michigan.

1. GLWQA Objective for whole fish.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Bloater data are from U.S. Fish & Wildlife Service; lake trout data are from a cooperative program of the U.S. Fish & Wildlife Service and U.S. Environmental Protection Agency, Great Lakes National Programs Office.

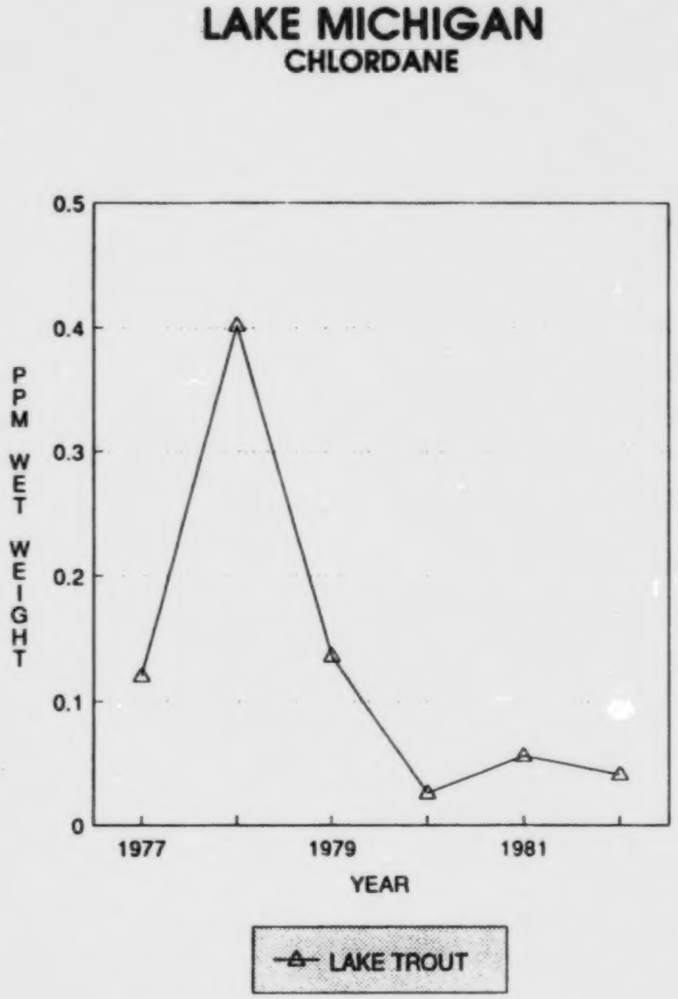


Figure 49

Mean concentrations of chlordane (ppm wet weight) in whole lake trout (620-640 mm mean length) from Lake Michigan.

Source: Devault *et al.*, 1986

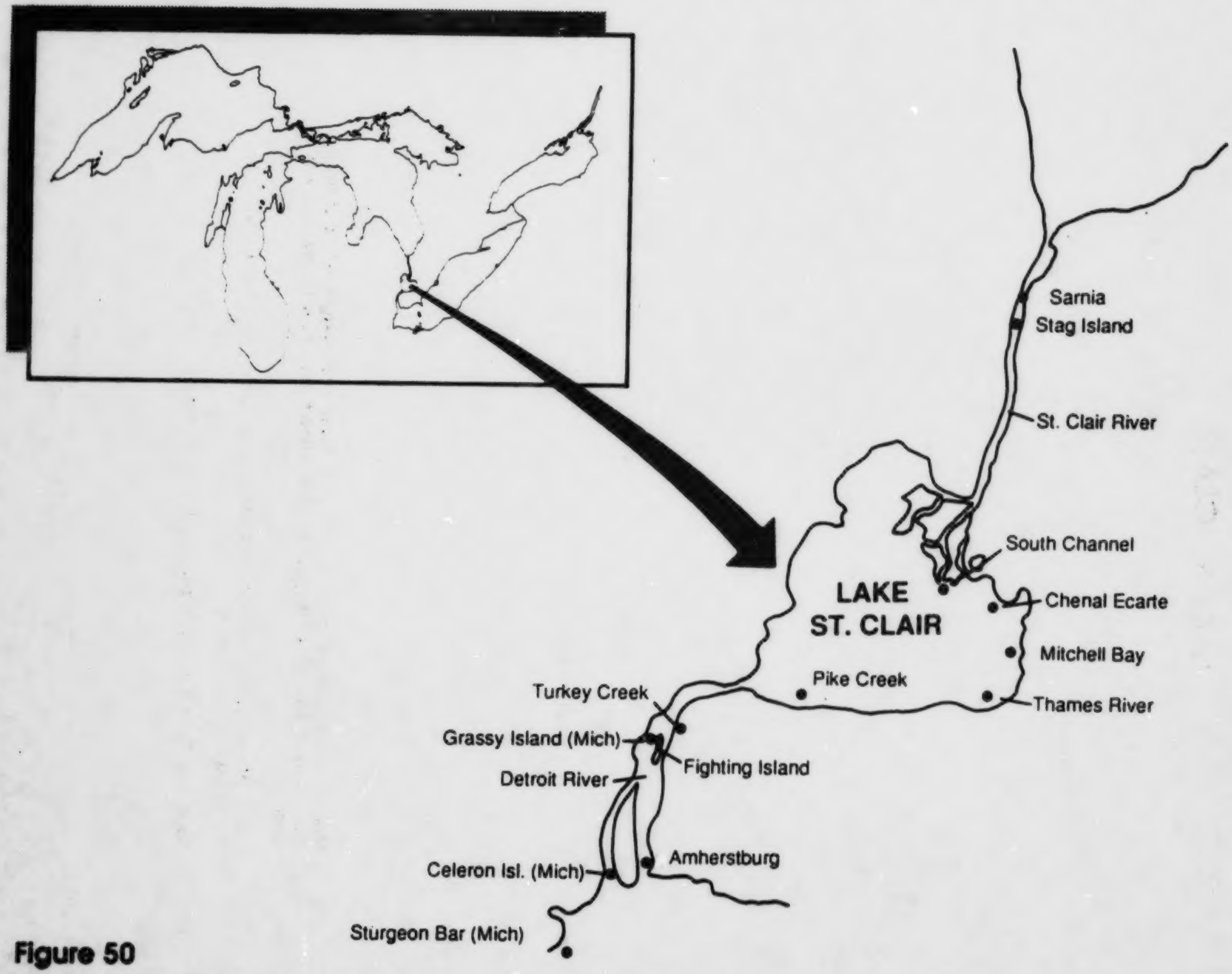

Sarnia
Stag Island
St. Clair River
South Channel
LAKE ST. CLAIR
Chenal Ecarte
Mitchell Bay
Pike Creek
Thames River
Turkey Creek
Grassy Island (Mich)
Fighting Island
Detroit River
Amherstburg
Celeron Isl. (Mich)
Sturgeon Bar (Mich)

Figure 50

Spottail shiner collection sites on St. Clair - Detroit River system.

LAKE ST. CLAIR

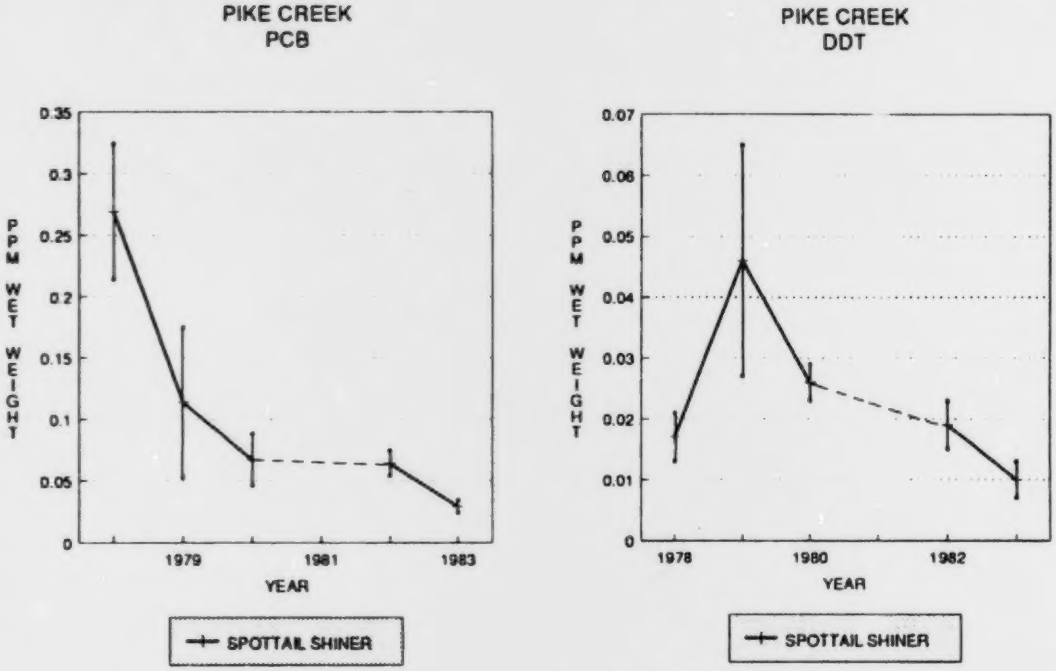


Figure 51

Mean concentrations of PCBs and DDT (ppm wet weight +/- standard deviation) in young-of-the-year spottail shiners from Pike Creek, Lake St. Clair.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: K. Suns, Ontario Ministry of the Environment.

LAKE ST. CLAIR
MERCURY

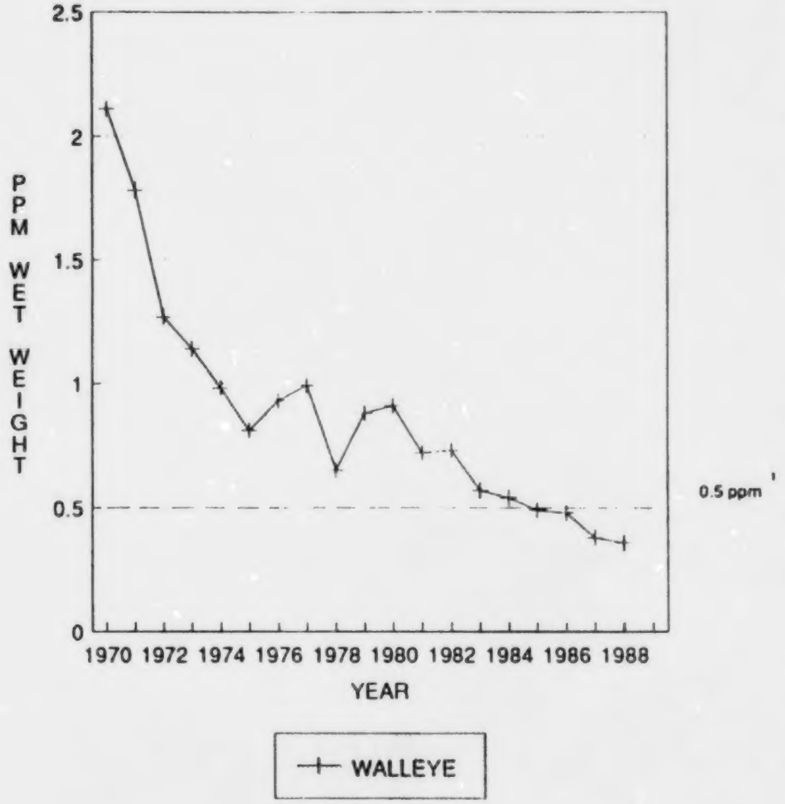


Figure 52

Mean concentrations of mercury (ppm wet weight) in walleye (dorsal muscle tissue) from Lake St. Clair.

1. NH&W Guideline for fish in commerce.

Source: Ontario Ministry of the Environment, and Ontario Ministry of Natural Resources. (Unpublished data)

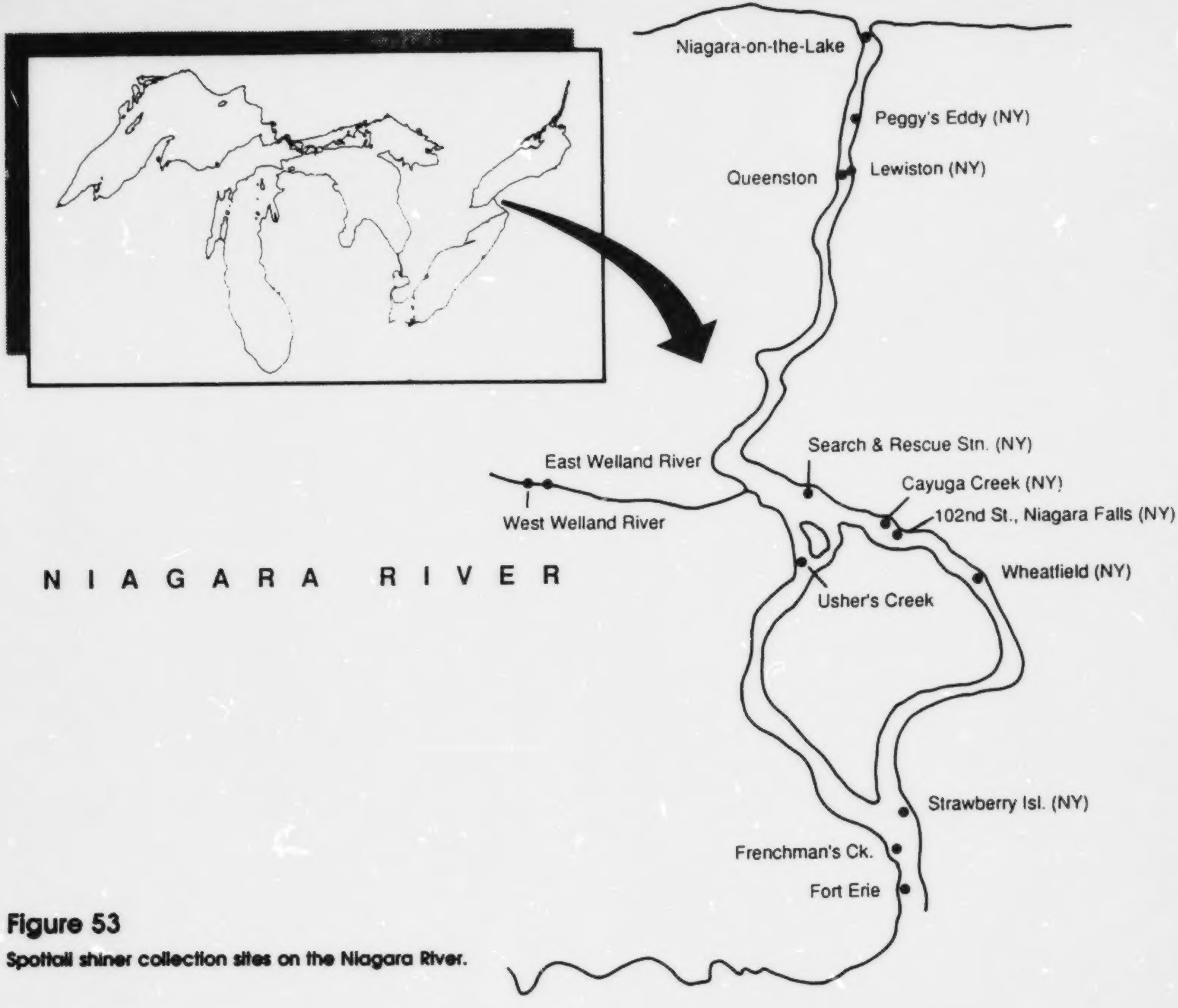

Niagara-on-the-Lake
Peggy's Eddy (NY)
Queenston
Lewiston (NY)
Search & Rescue Stn. (NY)
East Welland River
Cayuga Creek (NY)
West Welland River
102nd St., Niagara Falls (NY)
N I A G A R A R I V E R
Wheatfield (NY)
Usher's Creek
Strawberry Isl. (NY)
Frenchman's Ck.
Fort Erie

Figure 53

Spottail shiner collection sites on the Niagara River.

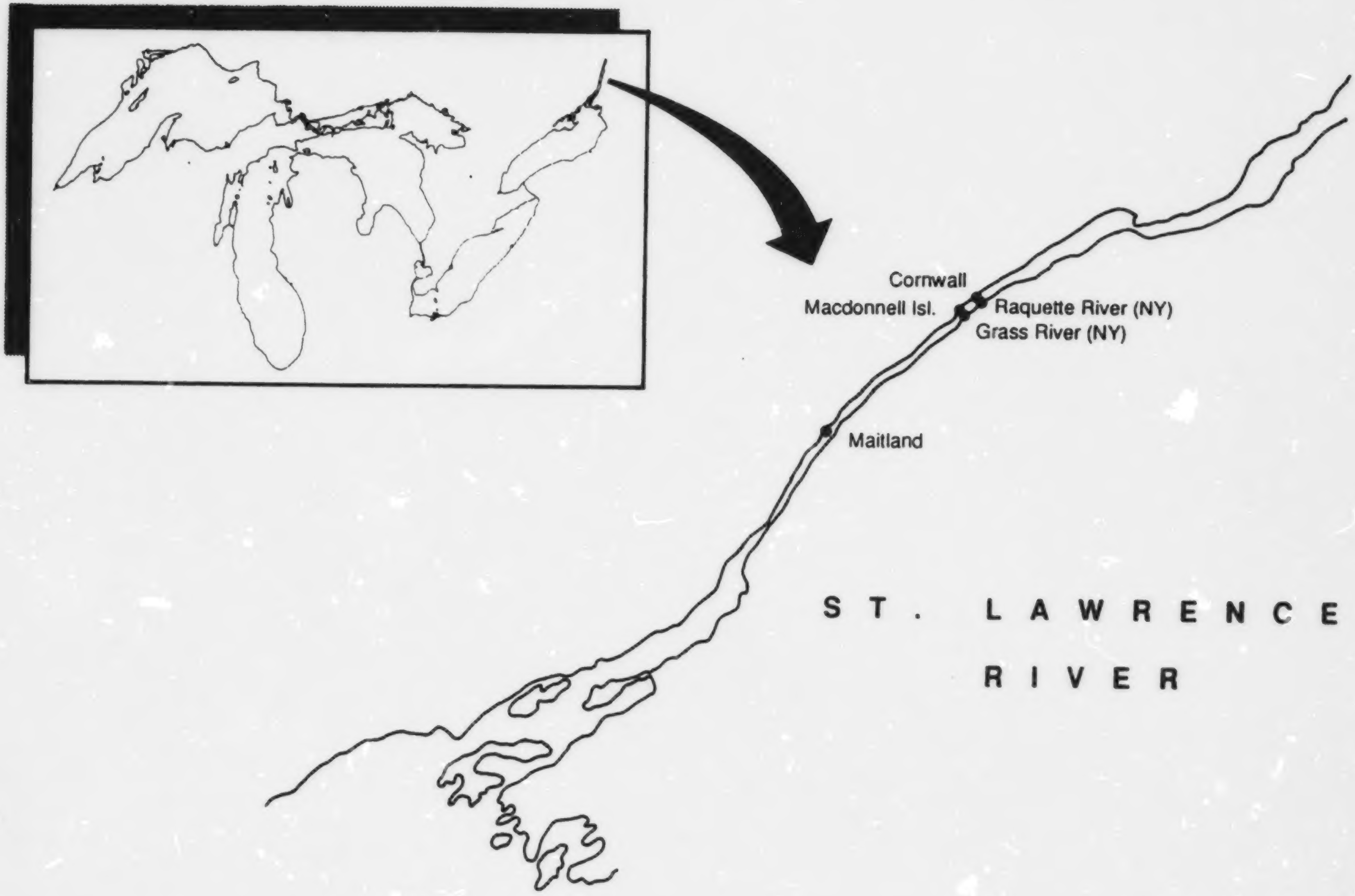

Cornwall
Macdonnell Isl.
Raquette River (NY)
Grass River (NY)
Maitland
ST. LAWRENCE
RIVER

Figure 54

Spottail shiner collection sites on the St. Lawrence River.

ST. LAWRENCE RIVER
LAKE ST. FRANCIS
MERCURY

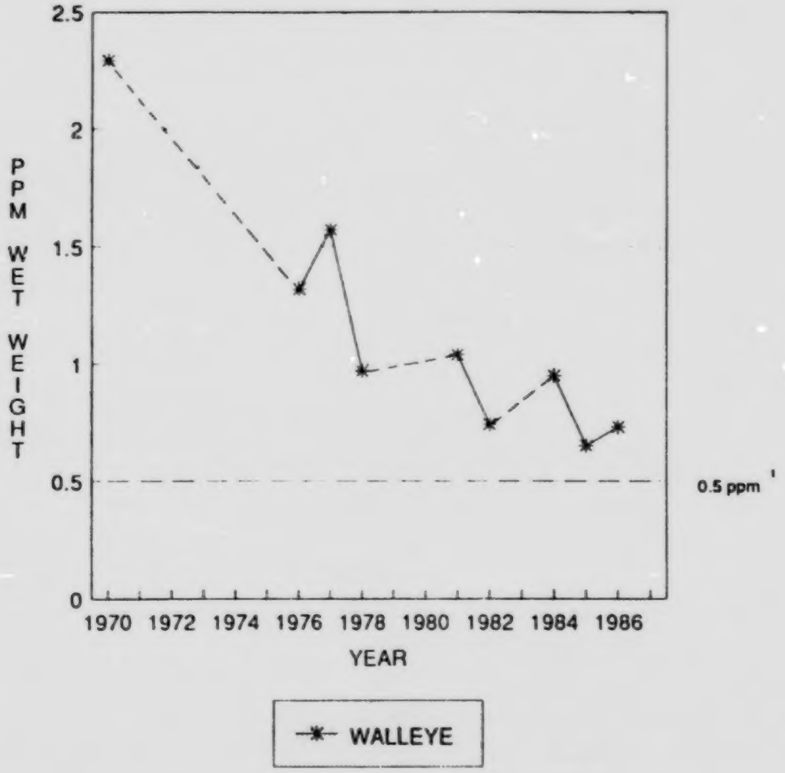


Figure 55

Mean concentrations of mercury (ppm wet weight) in walleye (dorsal muscle tissue) from Lake St. Francis, St. Lawrence River.

1. NH&W Guideline for fish in commerce.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Ontario Ministry of the Environment, and Ontario Ministry of Natural Resources. (Unpublished data)

ST. LAWRENCE RIVER
MAITLAND
ALKYL LEAD

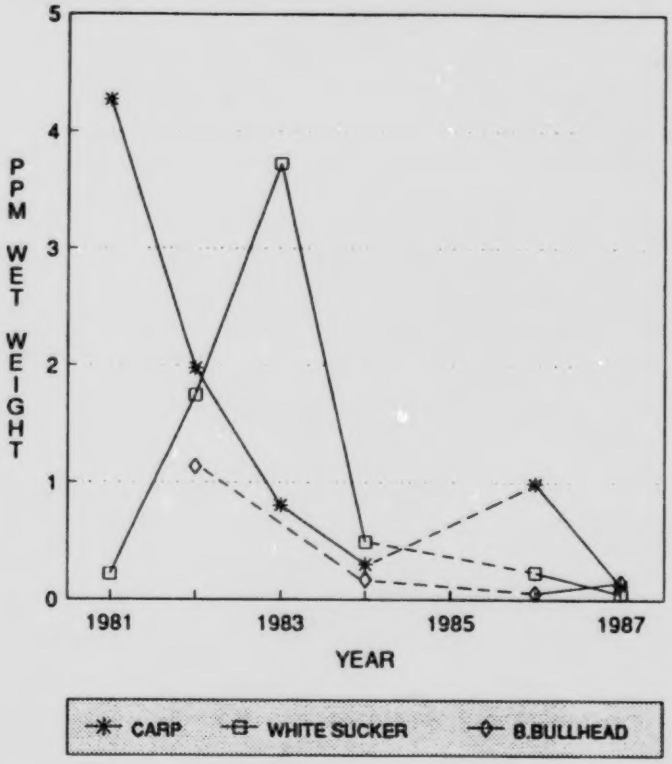


Figure 56

Mean concentrations of alkyl lead (ppm wet weight) in whole carp, white sucker and brown bullhead from Maitland, St. Lawrence River.

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

Source: Wong *et al.*, 1988

ST. LAWRENCE RIVER
MAITLAND
LEAD

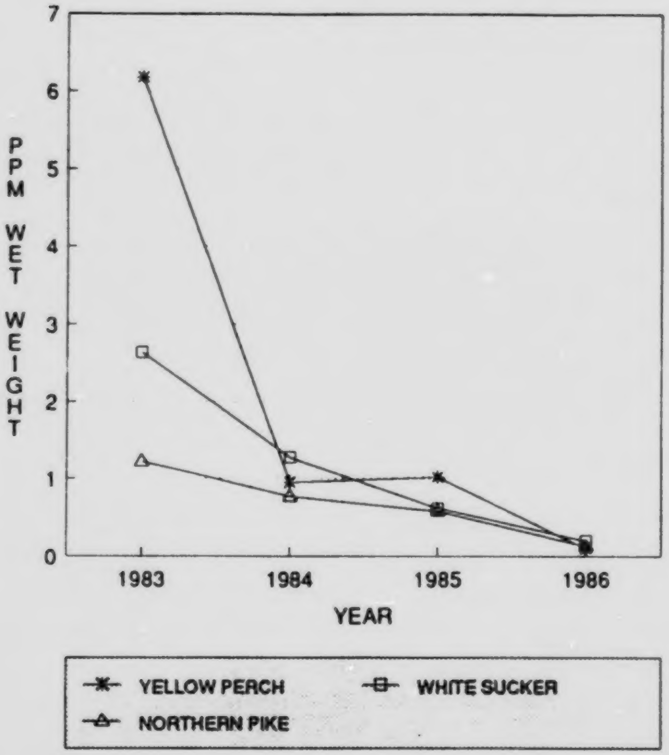


Figure 57

Mean concentrations of total lead (ppm wet weight) in yellow perch, white sucker and northern pike from Maitland, St. Lawrence River.

Source: Ontario Ministry of the Environment, and Ontario Ministry of Natural Resources. (Unpublished data)

WHOLE FISH PCB LEVELS
LAKE TROUT (Age 4)
PCB

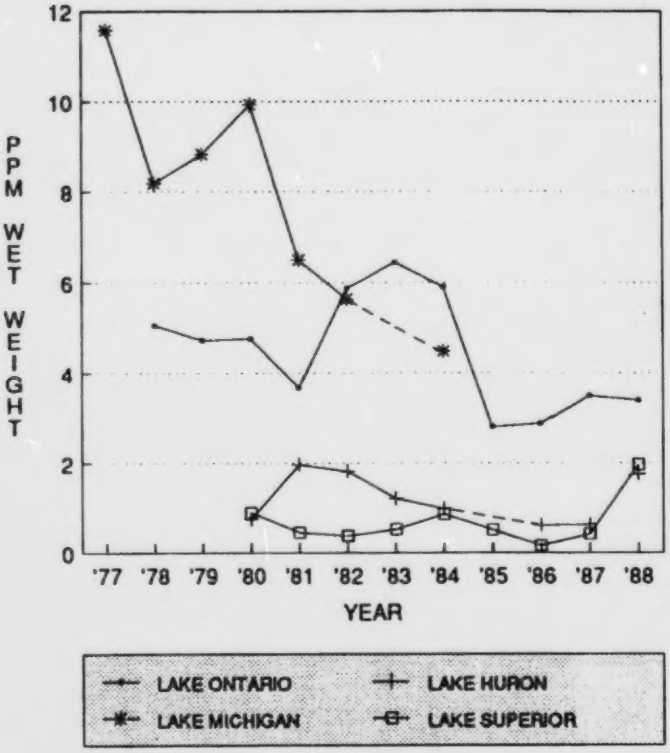


Figure 58

Mean concentrations of PCBs (ppm wet weight) by year in whole lake trout (age 4) from Lakes Ontario, Huron and Superior (DFO, Canada); whole lake trout (620-640 mm mean length) from Lake Michigan off Saugatuck, Michigan (Devault *et al.*, 1986)

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

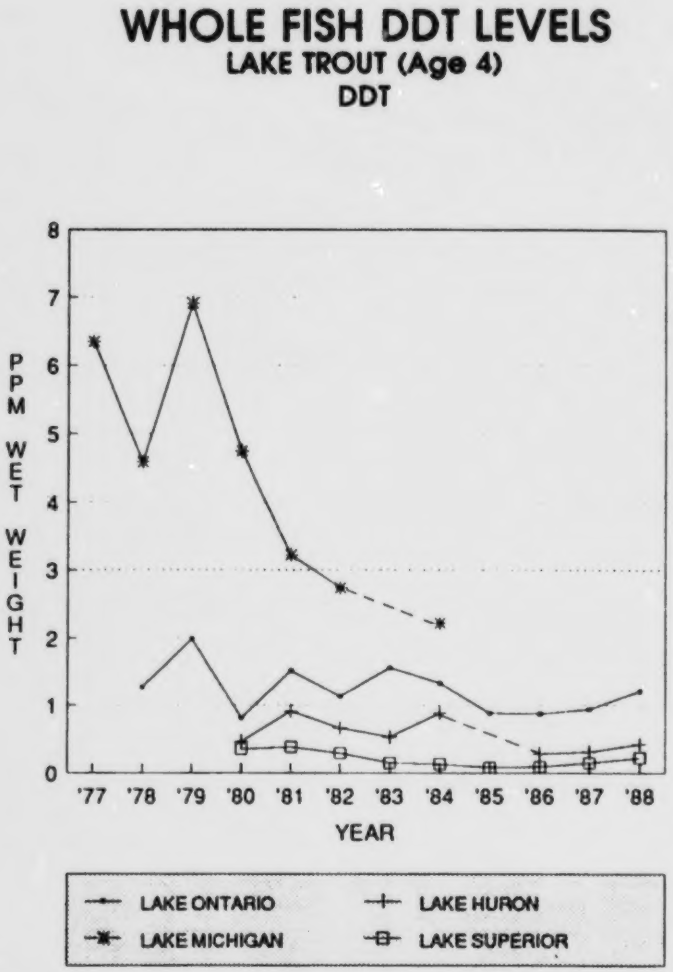


Figure 59

Mean concentrations of DDT (ppm wet weight) by year in whole lake trout (age 4) from Lakes Ontario, Huron and Superior (DFO, Canada); whole lake trout (620-640 mm. mean length) from Lake Michigan off Saugatuck, Michigan (Devault *et al.*, 1986).

Note: Where data are not available in consecutive years, dotted lines are used to estimate the trend.

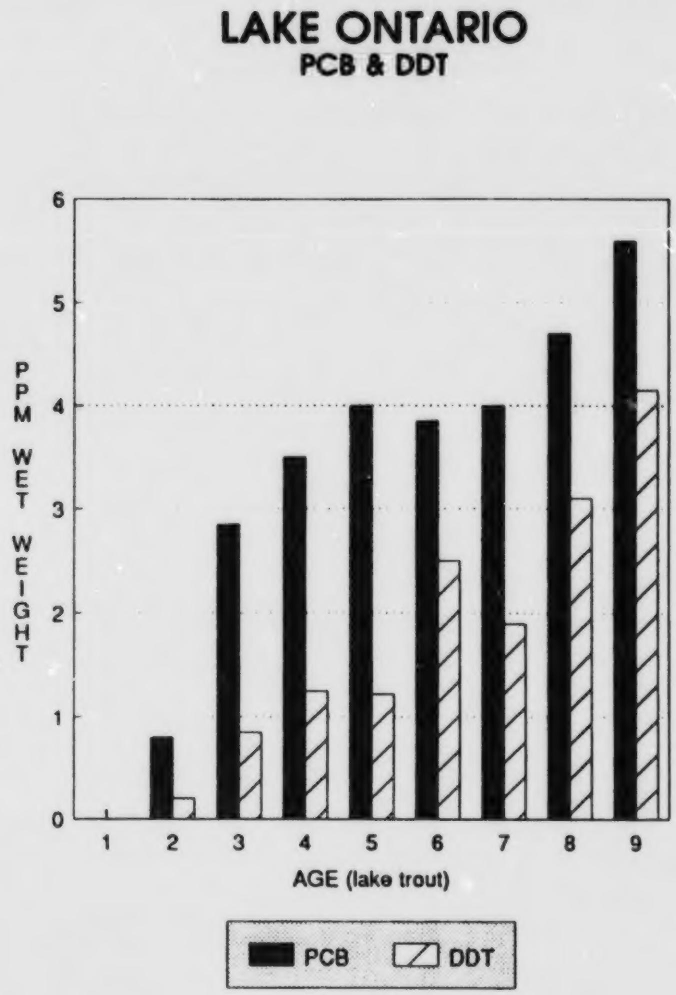


Figure 60

Concentrations of PCBs and DDT (ppm wet weight) in various age classes of whole lake trout from Lake Ontario in 1988.

Source: D.M. Whittle, Department of Fisheries and Oceans.

LAKE ONTARIO

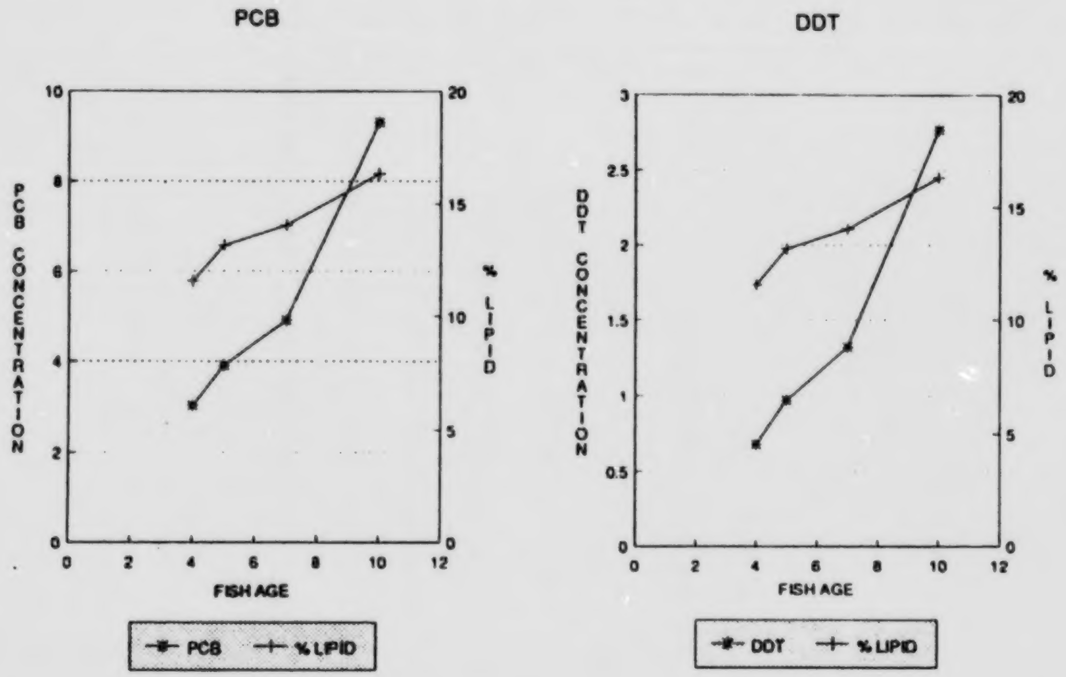


Figure 61

Concentrations of organochlorines in lake trout (standard fillets) from Lake Ontario as a function of age and lipid content (1985 collection).

Source: L. Skinner, NY Department of Environment and Conservation.

LAKE ONTARIO

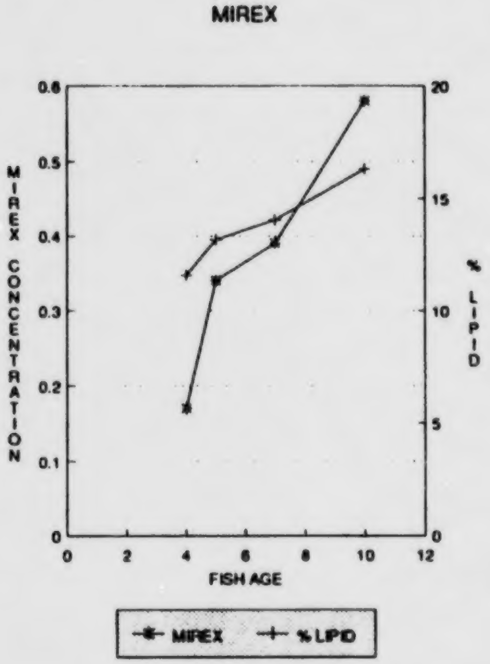


Figure 61 (continued)

Concentrations of organochlorines in lake trout (standard fillets) from Lake Ontario as a function of age and lipid content (1985 collection).

Source: L. Skinner, NY Department of Environment and Conservation.

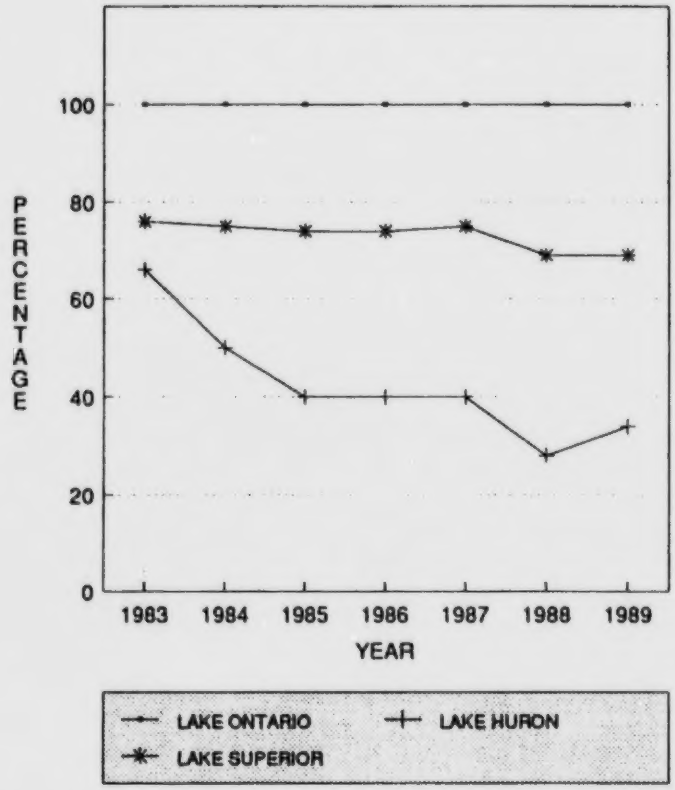


Figure 62

Proportion of lake trout collection sites with consumption advisories.

Source: J. Fitzsimons, Department of Fisheries & Oceans.

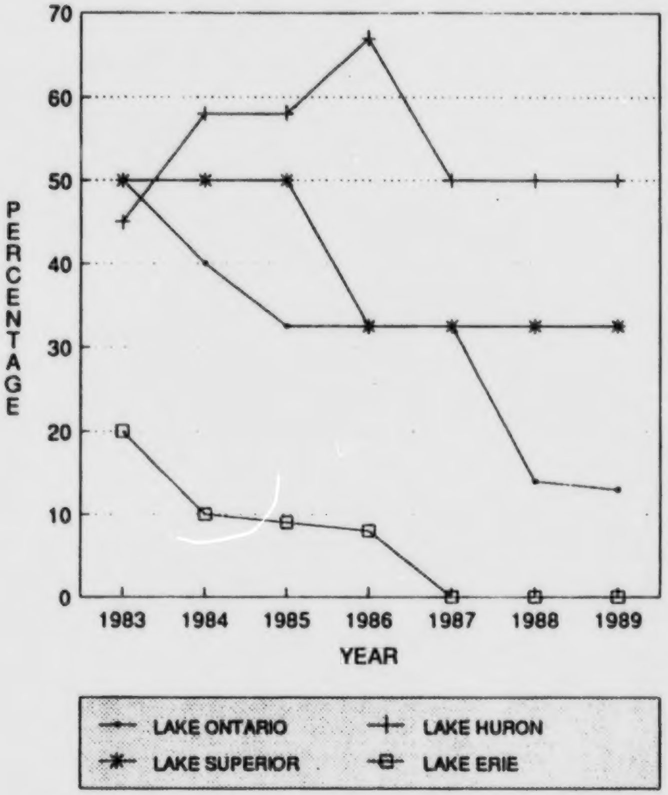


Figure 63

Proportion of yellow perch collection sites with consumption advisories.

Source: J. Fitzsimons, Department of Fisheries & Oceans.

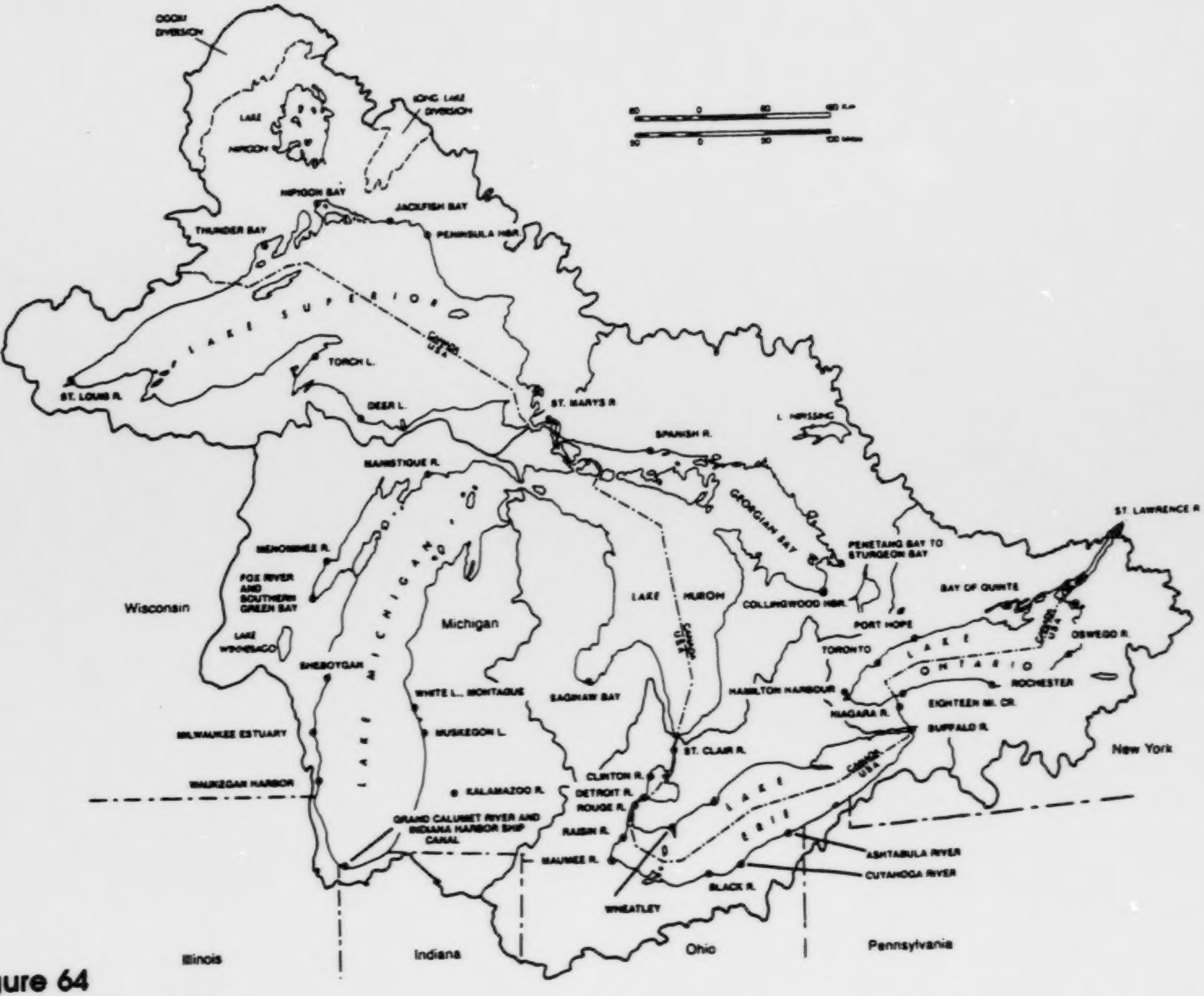

OGOKI DIVERSION
LONG LAKE DIVERSION
LAKE NIPIGON
NIPIGON BAY
JACKFISH BAY
PENINSULA HBR.
THUNDER BAY
LAKE SUPERIOR
CANADA USA
ST. LOUIS R.
TORCH L.
DEER L.
ST. MARYS R.
SPANISH R.
L. NIPISSING
MANISTIQUE R.
GEORGIAN BAY
PENETANG BAY TO STURGEON BAY
COLLINGWOOD HBR.
LAKE HURON
MENOMINEE R.
FOX RIVER AND SOUTHERN GREEN BAY
Wisconsin
LAKE WINNEBAGO
SHEBOYGAN
LAKE MICHIGAN
Michigan
WHITE L., MONTAGUE
MUSKEGON L.
SAGINAW BAY
MILWAUKEE ESTUARY
WAUKEGAN HARBOR
KALAMAZOO R.
GRAND CALUMET RIVER AND INDIANA HARBOR SHIP CANAL
ST. CLAIR R.
CLINTON R.
DETROIT R.
ROUGE R.
RAISIN R.
MAUMEE R.
WHEATLEY
BLACK R.
LAKE ERIE
ASHTABULA RIVER
CUYAHOGA RIVER
PORT HOPE
TORONTO
HAMILTON HARBOUR
NIAGARA R.
BUFFALO R.
EIGHTEEN MI. CR.
ROCHESTER
LAKE ONTARIO
BAY OF QUINTE
OSWEGO R.
ST. LAWRENCE R.
New York
Pennsylvania
Ohio
Indiana
Illinois
80 0 80 160 km
50 0 50 100 miles

Figure 64

Map of the Areas of Concern.

TOXIC CHEMICALS IN THE GREAT LAKES AND ASSOCIATED EFFECTS

VOLUME I PART 3

CONCENTRATIONS OF CONTAMINANTS IN WILDLIFE SPECIES

EXECUTIVE SUMMARY

Levels of organochlorine contaminants have been measured in wildlife samples from the Great Lakes since 1968. In the most extensive and largest established program, herring gull eggs collected throughout the Great Lakes have been analyzed. This program started in 1974 and it uses herring gulls as biological monitors of contaminant levels in the Great Lakes ecosystem. Concentrations of almost all of the organochlorines measured decreased significantly from the mid 1970s to the early 1980s. These include PCBs and the pesticides DDE, mirex and HCB. Since then contaminant levels in herring gull eggs (measured in ppm) have remained approximately the same. However, concentrations of dieldrin varied little over the entire time period. The reasons for this are unknown. TCDD (dioxin) data for Lake Ontario also show a decline for the early 1970s to the early 1980s. During the 1980s, there have been a few small but consistent oscillations in the concentration of most chemicals in herring gull eggs from across the basin. These oscillations have also been observed in concentrations of the same chemicals in fish during the same time period. Levels of mirex in herring gull eggs from Lake Ontario are approximately an order of magnitude higher than in samples from other lakes. Currently, the highest concentrations of PCBs are in eggs from colonies in Saginaw Bay, Lake Huron and Green Bay, Lake Michigan and along the Detroit River. 2,3,7,8-TCDD levels (measured in ppt) are highest in eggs from Saginaw Bay and Lake Ontario colonies.

Limited data from other avian species (cormorants, terns, night-herons) indicate a general decrease in organochlorine residues in eggs collected between 1971 and 1989. Historical data show evidence of elevated levels of contaminants in mink along the Lake Erie and Lake Ontario shorelines relative to levels inland. The presence of contaminants in snapping turtle eggs suggests there are local sources of contaminants near wetland areas. Although there is a shortage of historical data on this latter species, contaminant levels have not decreased since the mid 1980s.

Wildlife data are available on levels of only about twenty well-known organochlorine contaminants. Little is known about the presence of other xenobiotics in Great Lakes wildlife species.

Data on the well-known organochlorines show that levels have decreased. This coincides with restrictions and in some cases bans on the

use of these chemicals. Compliance with legislative restrictions on the production of these chemicals in Canada and the U.S. has led to a reduction of these chemicals from manufacturing and packaging sources on the Great Lakes. In recent years, however, concentrations in wildlife have equilibrated. This is probably because wildlife are still exposed to point sources not yet adequately controlled and to indirect sources such as resuspension of chemicals in sediments, long-range atmospheric transport, combined sewer overflows from urban areas, volatilization from contaminated soils and agriculture run-off. While the relative contributions of these sources are unclear, they are all difficult to control and remain chronic sources of organochlorine contaminants.

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1. INTRODUCTION

Several wildlife species in the Great Lakes aquatic ecosystem rely on fish as their primary food source. Part Three of this report summarizes the trends in contaminant residues of fish-eating birds, reptiles and mammals found in the Great Lakes basin. Four groups of species are considered:

1) Colonial nesting birds e.g., gulls, cormorants, terns, herons;
2) Raptorial birds e.g., bald eagles;
3) Mammals e.g., mink; and
4) Reptiles e.g., snapping turtles.

As top predators, these species are biological monitors of contaminants in the Great Lakes ecosystem. They are likely to accumulate the highest levels of organochlorine contaminant in the food web.

In 1968 the Canadian Wildlife Service (CWS) initiated studies to measure the levels of toxic contaminants in fish-eating birds because of reproductive failure and population decreases in double-crested cormorants, herring gulls and terns in the Great Lakes basin. The initial goal was to examine the relationship between levels of organochlorine compounds in eggs and reproductive failures (Gilbertson, 1974; Teeple, 1977; Gilman *et al.*, 1977a; Gilbertson and Fox, 1977; Postupalsky, 1978; Gilbertson, 1983; Mineau *et al.*, 1984). Early results from the program indicated that organisms from populations on Lakes Ontario and Michigan were among the most heavily contaminated in the world. This is because of the human population density and the industrial activity in the Great Lakes basin and because of the long range atmospheric transportation of contaminants into the region. The types and levels of residues found in wildlife were found to depend on the geographic location of the animal, prey selection, habitat preference and its position in the food web. Factors such as interspecies differences in metabolism and the proportion of body lipid were also identified as important.

Most levels discussed in this report are for organochlorine residues in bird eggs. In herring gulls, levels of organochlorines in eggs accurately reflect levels in the adult liver (Braune and Norstrom, 1989). It is likely that this relationship is valid for other species of fish-eating birds. When eggs are formed organochlorine compounds are translocated to them, together with the fat required to produce the yolk. Eggs are relatively easy to collect; it is not necessary to kill adult organisms. Females will usually replace lost eggs, if they are gathered early in the season.

This report contains a review of the available data on the levels of toxic chemicals in wildlife species. There is a large continuous data set on organochlorine residues in herring gull eggs, and trends in the levels of organochlorines such as PCBs, DDE, HCB, mirex, dieldrin and dioxin (2,3,7,8-tetrachlorodibenzo-p-dioxin, referred to as TCDD in the text) in eggs are discussed. Levels of these six contaminants in double-crested cormorants, caspian terns, common terns, black-crowned night-herons, bald eagles, mink and snapping turtles are also reviewed. Although there are reliable data for ring-billed gulls and Forster's terns, they are relatively sparse (both number of years and locations) and so have not been included in this report. In this report the emphasis is on temporal trends and inter-lake comparisons. Similarities between species and across taxa are also explored. Sampling locations are shown in Figure 1 for herring gulls, Caspian terns and double-crested cormorants; sampling locations for bald eagles and snapping turtles are shown in Figures 24, 26 and 27. Locations for black-crowned night-herons are the same as for other species.

The information base on organochlorine residues in waterfowl from the Great Lakes is very limited. The largest dataset has been compiled by the U.S. Fish and Wildlife Service for ducks shot by hunters in the continental U.S. Since 1981, New York State has issued annual waterfowl consumption advisories. Wisconsin established consumption guidelines in 1986. In Canada the most comprehensive survey was conducted by the Great Lakes Institute (1987) on game birds in Lake St. Clair. The interpretation of data on contaminants in wildlife is complicated by physiological and behavioural factors. Sampling protocols are now under development by the Canadian Wildlife Service to minimise the role of these variables. There is a need for a comprehensive monitoring program on waterfowl and for the development of Canadian consumption guidelines to assist hunters. The Department of National Health and Welfare has recently released (1990) consumption guidelines for diving ducks in British Columbia. As yet there are not Canadian consumption guidelines for wild ducks in the Great Lakes basin.

2. HERRING GULL

The herring gull is an indicator of the levels of toxic chemicals in the Great Lakes ecosystem (Mineau *et al.*, 1984). As a fish-eater (mainly alewife and rainbow smelt), it is a top predator in the Great Lakes aquatic food web. The herring gull's diet also consists of mammals, insects, birds and bird eggs, amphibians, earthworms, garbage and crayfish. Fish, however, are the most important food item (Fox *et al.*, 1990). Of the various species of fish-eating birds that could have been used as an indicator the herring gull is the one that stays on the lakes all year (Moore, 1976). Other colonial waterbirds such as terns, cormorants and other species of gull migrate annually and therefore could accumulate a proportion of their contaminant loads outside the basin. It is extremely unlikely that birds from outside the Great Lakes region have inadvertantly been included in the herring gull sampling program (Weseloh, 1984). Finally, herring gulls are abundant and breed in all five Great Lakes (although there are no colonies in southern Lake Michigan), so that inter-lake comparisons are possible. A recent analysis (Weseloh *et al.*, 1990) suggests that under certain circumstances, residue levels in herring gull eggs can also indicate regional contamination.

Herring gull eggs have been collected and analyzed from colonies throughout the Great Lakes since 1974 as part of a long term toxic chemical monitoring program undertaken by the Canadian Wildlife Service. The same 13 sites have been visited each year (Figure 1). Between 10 and 13 fresh eggs are collected at each site and they are now analyzed for up to 20 organochlorine compounds, 41 PCB congeners and 9 dioxin and furan congeners. The earlier results of the program have been reviewed by Mineau *et al.* (1984). Recent results from the program have been published in Stalling *et al.* (1985), Struger *et al.* (1985), Norstrom *et al.* (1986), IJC (1987), Braune and Norstrom (1989), and Bishop *et al.* (in prep.). The organochlorine data are based on individual analyses of 10 eggs from each colony with the following exceptions: all TCDD results are based on one pooled analysis of 10 eggs per colony, data after 1985 for other compounds are also based on a single analysis of a 10 egg pool for each colony. The average lipid levels in eggs on a per colony basis ranged from 8.4 to 10.0%. Data are presented for two colonies in each Great Lake (three for Lake Huron) and for colonies on the Niagara and Detroit Rivers. The results are shown for each colony and residue concentrations are provided to illustrate temporal trends.

PCB congeners

There are a total of 209 possible congeners of PCBs which are identified by the number and relative position of chlorine atoms on the biphenyl structure. Congener-specific analyses show that there are different patterns of accumulation of individual PCBs in organisms. Selective bioaccumulation occurring in the alewife-herring gull food chain shows a dependence on the chlorine substitution pattern of PCB congeners.

Early concentrations of PCBs in herring gull eggs were based on a mixture of Aroclor 1254/1260 1:1. These results are about double the more useful and accurate measure of PCBs known as Σ PCB (sum of 41 PCB congeners). Recently, conversion factors have been calculated for the Aroclor 1254/1260 1:1 mixture to Σ PCB. They are as follows: Lake Ontario 0.466; Lake Erie 0.448; Lake Huron 0.487; Lake Superior 0.453; Lake Michigan and connecting channels 0.464 (R. Turle, CWS, pers. comm.). These factors are for herring gull eggs; equivalent factors have not been determined for other tissues or species. Great care must be taken when comparing PCB levels in this report to other published values which may be based on either different analytical methodology, standards or different Σ PCB values using different sets of PCB congeners. In this report, PCB values cited for herring gull eggs are Σ PCB values. Except for recent snapping turtle data, all other results are based on Aroclor 1254/1260 1:1 mixture standards.

2.1 LAKE ONTARIO

The results discussed in this section are based on eggs collected from Snake Island on the western end of the St. Lawrence River and from Mugg's Island on the Toronto waterfront. Data for TCDD were also collected from Hamilton Harbour and Scotch Bonnet Island (Figure 1). Levels from 1974 to 1989 are shown by colony and by contaminant. In 1989, contaminant levels in herring gull eggs from Lake Ontario were well below the levels recorded in 1974.

Since 1974, Σ PCB levels in gull eggs from Mugg's and Snake Islands decreased from 77 and 65 ppm, respectively, to 16 and 14 ppm, respectively. During the last four years the decline has slowed (Figure 2). DDE levels show a similar pattern and have levelled off at approximately 5 ppm (Figure 2).

Levels of mirex in eggs from Lake Ontario colonies (Figure 3) are an order of magnitude higher than in eggs from other Great Lakes (Figures 5, 10, 14, 19, 22). This is because of two historical sources: a manufacturing plant on the Niagara River and a distribution plant at Oswego, New York. From 1974 until 1978, the levels of mirex in gull eggs decreased rapidly, the rate being similar to that found experimentally in young herring gulls (Clark *et al.*, 1987). The manufacturing plant closed in 1976. Recent residue concentrations in the Lake Ontario colonies have levelled off at approximately 1 ppm. This probably reflects continued input from indirect sources such as long range transport and re-suspension from sediments.

HCB residues in eggs from Snake Island and at Mugg's Island have decreased steadily (Figure 3). Over the last four years, however, there has been no real change in HCB concentrations at either colony with concentrations levelling off below 0.1 ppm.

As with the other organochlorines, levels of dieldrin in eggs from both colonies are lower today than they were in 1974 (Figure 4), although the decreases are not as dramatic as those in concentrations of other organochlorines. These levels have varied little in the last 4 to 5 years.

TCDD levels have been determined in eggs from four colonies on Lake Ontario (Figure 4). There was a two-fold decrease in TCDD concentrations in eggs from the Snake Island colony between 1981 and 1984. Since then, levels have remained relatively constant, although there have been minor oscillations or slower decreases. In 1989, TCDD levels were 91 ppt. A longer time series of TCDD values has been determined from archived samples stored in the Canadian Wildlife Service's National Tissue Bank (Elliot, 1984). These samples were collected from a colony on Scotch Bonnet Island, near Brighton off the north shore of Lake Ontario. The data cover the period 1971-82. A significant decrease occurred from 2000 ppt in 1971 to 204 ppt in 1982. Levels in eggs from Hamilton Harbour (1984-88) were lower, but did not decrease. Between 1981 and 1989, TCDD residue levels in eggs from colonies on Lake Ontario and Saginaw Bay (Lake Huron) were at least double those in all other Great Lakes colonies. The high level in eggs from Lake Ontario is probably because there used to be a chemical plant on the Niagara River that produced 2,4,5-trichlorophenol. TCDD can be formed during the production of this chemical and contaminants in the waste water could have entered the Niagara River, and then Lake Ontario. Production of 2,4,5-trichlorophenol was discontinued in the mid-1970s and subsequently TCDD residues in eggs collected from the Scotch Bonnet colony decreased. However, residues in eggs from Lake Ontario remain higher than those in eggs from other lakes. "Background levels" of PCDDs and PCDFs (10-20 ppt for TCDD) can be attributed to atmospheric deposition (Norstrom, in preparation).

Most of the data on organochlorine residues in eggs from Lake Ontario colonies show a small increase occurring in 1981/82 and possibly 1984/85. Although the reasons for these increases are unclear, it could be because:

1) Sporadic pulses from point source discharges or sediment recycling occur;
2) Changes in the food web can occur, such as cycles in fish populations which could affect the gulls' diet and their contaminant levels (Fox *et al.*, 1990); and
3) Some as yet unidentified climatic variable.

The 1981/82 increase in contaminant levels in herring gull eggs from Lake Ontario was reflected in similar changes in colonies on other lakes and in fish.

2.2 NIAGARA RIVER

The gull eggs discussed in this section were collected from an unnamed island located approximately 300 metres upstream from the edge of Niagara Falls on the Canadian side of the river (Figure 1). Data are available from 1979 to 1989.

Σ PCB and DDE residues have steadily decreased since 1979 and 1981, respectively (Figure 5). Mirex residues in gull eggs from the Niagara River have fluctuated, with the maximum concentration occurring in 1982. In 1988, levels were within an order of magnitude of eggs collected from Lake Ontario colonies and higher than residue levels in eggs from colonies on the other lakes (Figure 5). HCB residues decreased during the study period. Dieldrin levels have shown little change since 1979 and continue to fluctuate at approximately 0.2 ppm (Figure 6). There is a similar pattern to dieldrin levels in eggs from other sites. Data on concentrations of TCDD are available from 1981 to 1989. They show an overall decrease from 87 to 18 ppt, although they have been fluctuating since 1983 (Figure 6). There was a small increase in 1984 in levels of TCDD, dieldrin, HCB and mirex in gull eggs taken from this colony.

2.3 LAKE ERIE

The gull eggs discussed in this section were collected from Middle Island, in the western basin, and Port Colborne Lighthouse, in eastern Lake Erie (Figure 1). Current residues of Σ PCB, DDE, mirex and HCB are well below those recorded in 1974.

Σ PCB residues have decreased at both locations (Figure 7) and 1989 levels are similar to those found in eggs at herring gull colonies on Lake Ontario. In 1981/2 and 1984/5, there were small increases in both colonies.

Levels of DDE have decreased in eggs collected from Middle Island and Port Colborne, however, the temporal trends were initially dissimilar. From 1974 to 1978, levels at Middle Island first increased and then decreased rapidly. In contrast, DDE burdens in gull eggs from Port Colborne decreased steadily during this period. Since 1978, concentrations have levelled off in both populations. The 1981/2 rise is visible in the Port Colborne sample but did not occur in eggs from Middle Island. Levels in eggs from both colonies are now approximately 2 to 3 ppm, compared to levels of 6-9 ppm in 1974 (Figure 7).

Mirex levels in eggs from Middle Island decreased from 0.44 ppm in 1974 to 0.03 ppm in 1989. Temporal trends indicate that there was a rapid initial decrease followed by a levelling off starting in 1978. The concentration of mirex in eggs from Port Colborne in 1989 (0.32 ppm) is an order of magnitude greater than in eggs from Middle Island. The Port Colborne Lighthouse colony is within foraging distance of the Niagara River (where there was a point source of mirex for several years) and Lake Ontario. Residue levels in this colony have fluctuated widely, but have levelled off in the last five years at between 0.2 and 0.4 ppm (Figure 8).

HCB levels in gull eggs from Middle Island and Port Colborne show a rapid initial decrease occurring from 1974 to 1977. This is consistent with the relatively short half-life calculated for this compound (Clark *et al.*, 1987). Since then, concentrations have levelled off.

Dieldrin residues in gull eggs from the two Lake Erie colonies have not decreased as rapidly as concentrations of other organochlorines. Levels have continued to fluctuate at approximately 0.2 ppm since 1980 (Figure 9). Since the half-life of dieldrin is similar to that of HCB (Clark *et al.*, 1987) this suggests that there may be substantial inputs still occurring.

Data on TCDD levels are available from 1981 to 1989 for the Middle Island gull colony. They show an overall decrease from 25 ppt in 1981 to 16 ppt in 1989, but an increase occurred from 1983 to 1987 (Figure 9). Data from the Port Colborne colony for 1984 to 1989 show no discernable trends. TCDD levels were greater in the Port Colborne colony.

Organochlorine levels in gull eggs from Lake Erie colonies were lower than those in eggs from Lake Ontario colonies. In recent years, contaminant concentrations have not decreased as rapidly as they did in earlier years.

2.4 DETROIT RIVER

From 1978 to 1989, herring gull eggs have been collected from Fighting Island on the Detroit River (Figure 1). Levels of all six organochlorines decreased, except for dieldrin. Σ PCB levels decreased from 65 ppm in 1979 to 27 ppm in 1989. Since 1982, PCB residue levels have been fluctuating between 20 and 40 ppm in gull eggs from Fighting Island (Figure 10). DDE levels have also decreased during the study period (9.4 ppm in 1978 to 2.2 ppm in 1989) and have levelled off since 1983 (Figure 10).

Mirex levels in gull eggs from the Detroit River decreased, showing the same trend observed in other colonies. However, from 1982 to 1985 there was an anomalous increase, during which levels went as high as 0.37 ppm (in 1985). This was nearly three times the values recorded in previous years. Levels have since decreased and gull residues recorded in 1984 were 0.04 ppm, similar to those in eggs from other sites outside Lake Ontario (Figure 10).

HCB levels in gull eggs from the Detroit River decreased steadily from 1979 (0.33 ppm) to 1989 (0.05 ppm) (Figure 10). Dieldrin levels fluctuated over the study period and showed no clear trends. Levels ranged from 0.24 ppm in 1982 to 0.06 ppm in 1989 (Figure 11).

Gull eggs from Fighting Island have been analyzed for TCDD since 1981. Levels have decreased from 49 ppt in 1981 to 13 ppt in 1989 (Figure 11).

2.5 LAKE HURON

The herring gull eggs discussed in this section were taken from three Lake Huron colonies: Double Island in Georgian Bay, Chantry Island in the main basin: and Channel/Shelter Island in Saginaw Bay (Figure 1). Data for the main basin colonies (1974 to 1989) are shown by contaminant. Data from Channel/Shelter Island are available from 1980 to 1989.

Σ PCB levels in gull eggs decreased from 27 ppm in 1974 to 7 ppm in 1989 at Double Island and from 42 to 3 ppm at Chantry Island (Figure 12). Since 1980, Σ PCB levels have equilibrated, except for the peak in 1981/2. In the Saginaw Bay colony, Σ PCB levels have decreased only slightly from 34 to 28 ppm, and are considerably higher than levels in eggs from the other two colonies on Lake Huron.

Residues of DDE (Figure 13) have decreased in eggs from all three colonies. Concentrations decreased first and most rapidly in eggs from Chantry Island, although this was followed by a levelling off. Levels are higher in eggs from Channel/Shelter Island in Saginaw Bay (7 ppm). These high levels were probably due to historic uses of DDT in the Saginaw River/Bay watershed.

Mirex levels in eggs from Double and Channel/Shelter Islands show downward temporal trends (Figure 14). In 1974, the Chantry Island colony had high levels (2.2 ppm). These levels are comparable to those in Lake Ontario. Residue levels subsequently dropped to 0.05 ppm in 1989. There have been no major changes in levels in this colony since 1977.

HCB concentrations in the Chantry and Double Island colonies show a similar trend, with a rapid initial decrease occurring from 1974 to 1979 followed by a levelling off at approximately 0.02 ppm. Higher HCB burdens were found in the 1981 - 1989 Channel/Shelter Island samples, however, since 1984 levels have fluctuated at below 0.1 ppm (Figure 15).

As reported for colonies on the other lakes, dieldrin levels in eggs did not decrease rapidly in Double and Chantry Islands on Lake Huron between 1974 and 1989. Dieldrin residues in gull eggs from Channel/Shelter Island show no apparent decrease from 1980 to 1989 (Figure 16).

Levels of TCDD in gull eggs from Double Island have been measured since 1984, but there are no apparent trends (Figure 17). This may be because these levels can be attributed to particulates from combustion (Norstrom, in preparation). Analyses of eggs collected from Chantry and Channel/Shelter Islands were done from 1981 to 1989. Levels in eggs from Chantry Island decreased from 1982 to 1989 (61 ppt - 12 ppt). Concentrations at Channel/Shelter Island are considerably higher and decreased from 214 ppt in 1982 to 78 ppt in 1989. These levels are equivalent to the residues measured in eggs from Lake Ontario colonies. They are considerably higher than current levels at all other colonies on the Great Lakes. These data suggest that the 2,4,5-trichlorophenol manufacturing plant on the Tittabawassee River, Michigan, which flows into Saginaw Bay, is a source of TCDD (Norstrom, in preparation).

In summary, levels of Σ PCB, DDE and HCB were lowest in the Double Island colony on the North Channel. Levels of TCDD, Σ PCB, mirex and DDE were highest at the Channel/Shelter Island colony in Saginaw Bay.

2.6 LAKE MICHIGAN

The herring gull eggs discussed in this section were taken from two colonies: Gull Island at the North end of the lake and Big Sister Island in Green Bay (Figure 1). Eggs from Big Sister Island were collected from 1971 to 1989 and from Gull Island from 1978 to 1989.

Trends in Σ PCB burdens were similar at the two sites. Residues decreased in the late 1970s and early 1980s. Since 1983, they have levelled off between approximately 10 and 20 ppm. Overall concentrations at Big Sister Island ranged from 77 ppm in 1973 to 10 ppm in 1989 and from 42 ppm in 1978 to 10 ppm in 1989 at Gull Island (Figure 18).

The trend in DDE levels in eggs collected from the two colonies shows that a rapid decrease occurred in the 1970s. This was followed by a levelling off in the 1980s. Since 1983, DDE concentrations in eggs from Big Sister Island and Gull Island have levelled off at approximately 5 ppm (Figure 18).

The highest concentration of mirex was recorded in the 1971 samples from Big Sister Island (0.68 ppm). Temporal data for both colonies show that residues decreased and then levelled off in the 1980s (Figure 19).

HCB levels in eggs from the Big Sister Island colony fell from 0.42 ppm in 1971 to less than 0.1 ppm during the 1980s. Residue levels at Gull Island were also below 0.1 ppm (Figure 19).

As in other colonies, dieldrin levels in eggs from the Lake Michigan sites have not decreased as rapidly as other organochlorines (Figure 20). Samples on Gull Island show slight decreases while 1987 levels in eggs from Big Sister Island were actually higher than those in 1971.

TCDD levels from Big Sister Island decreased dramatically between 1971 and 1972, then decreased more gradually to the present. In the last four years concentrations have levelled off to a 'background level' of between 10 and 20 ppt (Norstrom, in preparation). Dioxin levels in eggs from Gull Island are also in this range (Figure 20).

2.7 LAKE SUPERIOR

The herring gull eggs discussed in this section were taken from the Granite Island and Agawa Rock colonies (Figure 1). Residue levels from 1974 to 1989 are shown. Levels of Σ PCB, DDE, mirex and HCB are lower today than they were in 1974.

As in colonies on other lakes, Σ PCB levels decreased with concentrations levelling off at approximately 7 ppm in the late 1980s (Figure 21). Levels of DDE, although initially higher in eggs from Granite Island, also showed a similar decreasing trend in both colonies. Since 1980, concentrations have levelled off at between 2 and 7 ppm. The 1981/82 increase in contaminants reported in other colonies can be seen in eggs from both Lake Superior colonies for both PCB and DDE residues (Figure 21).

In 1974, mirex concentrations at the Granite Island colony were greater than the levels at Agawa Rock. However, Granite Island levels show a steady decline over the period of record (from 1.3 to 0.04 ppm). Agawa Rock residue levels declined from 0.76 ppm in 1974 to 0.09 in 1989. In the last four years residue levels appear to have levelled off in both colonies (Figure 22).

In 1974, HCB levels in eggs from Granite Island were 0.22 ppm. Since then they have steadily decreased. Samples from Agawa Rock showed year-to-year variations (from 0.14 to 0.08 ppm between 1979 and 1980) but levelled off in 1983. Concentrations in eggs from both colonies remain at approximately 0.05 ppm (Figure 22). The decrease in eggs from Granite

Island from 0.22 to 0.06 ppm is substantial.

As in eggs from Lake Erie colonies, dieldrin levels have fluctuated with no apparent trends (Figure 23). In 1989, levels were approximately 0.3 ppm.

Residues of TCDD have been monitored since 1984 in eggs from Granite Island. Concentrations have fluctuated between 14 and 19 ppt ('background' levels). There have been no apparent trends (Figure 23). At Agawa Rock, where the eggs have been monitored since 1981, TCDD levels decreased in 1982 and 1983, but since 1984 they have fluctuated. The highest level at this colony was 79 ppt in 1981 and the lowest level was 13 ppt in 1983.

2.8 INTER-LAKE COMPARISONS

Inter-lake comparisons are valid because gulls spend most of their time in the lake where they breed, although there is some limited inter-lake movement in the winter. For example, banding recoveries have shown that adult gulls from Lake Superior overwinter in Lake Michigan and Lake Erie birds have been found in the Niagara River in the winter (Gilman *et al.*, 1977b). However, within each lake, herring gulls stay in the vicinity of their colony for much of the year and are thus good integrators of contamination on a regional basis (Weseloh, 1984).

Levels of organochlorines in gull eggs from Lakes Ontario and Michigan have remained higher than at other lakes throughout the entire period of monitoring. Herring gull eggs from Lake Ontario have the highest residues of TCDD, mirex and HCB (Table 1). However, concentrations in Lake Ontario eggs have decreased the most. Eggs from Lake Michigan have been most heavily contaminated with DDE and dieldrin, but least contaminated with TCDD. The Channel/Shelter Island colony in Saginaw Bay, Lake Huron is notable for having the highest levels of Σ PCB and DDE and high TCDD levels.

Eggs from other colonies on Lake Huron have the lowest levels of Σ PCB and TCDD, while eggs from Lake Michigan have the lowest concentrations of HCB. Eggs from Lake Erie had neither the highest nor the lowest concentrations of any chemical.

TABLE 1. MEAN CONCENTRATIONS OF ORGANOCHLORINES[1] (ppm[2], wet weight basis) IN HERRING GULL EGGS FROM ANNUAL MONITOR COLONIES ON THE GREAT LAKES, 1989.

	Σ PCB congeners	DDE	MIREX	HCB	DIELDRIN	TCDD	%LIPID
LAKE ONTARIO							
SNAKE ISLAND	14	5.2	1.1	0.07	0.14	91	8.6
MUGG'S ISLAND	16	5.3	1.2	0.06	0.30	55	7.9
NIAGARA RIVER							
ISLAND ABOVE FALLS	9	2.1	0.24	0.04	0.13	18	8.4
LAKE ERIE							
PORT COLBORNE	17	3.1	0.33	0.05	0.23	19	10
MIDDLE I.	21	2.2	0.03	0.05	0.11	16	8.8
DETROIT RIVER							
FIGHTING I.	27	2.2	0.04	0.05	0.06	13	7.5
LAKE HURON							
CHANTRY I.	3.1	0.77	0.05	0.03	0.15	12	8.7
DOUBLE I.	7.1	2.4	0.14	0.04	0.25	18	8.8
CHANNEL/ SHELTER I.	28	7.0	0.09	0.08	0.15	78	8.2
LAKE SUPERIOR							
GRANITE I.	7.2	2.4	0.05	0.06	0.34	16	7.6
AGAWA ROCK	6.8	2.6	0.09	0.04	0.33	19	7.5
LAKE MICHIGAN							
BIG SISTER I.	9.9	4.7	0.03	0.04	0.58	10	8.7
GULL I.	9.4	5.0	0.04	0.05	0.53	11	8.8

1. Data are based on a single analysis of a 10 egg pool for each colony except TCDD which is based on a 10-egg pool.
2. All values are in ppm except TCDD, which is in ppt.

Source: D.V. Weseloh, Canadian Wildlife Service; TCDD data, R.J. Norstrom, Canadian Wildlife Service.

2.9 DISCUSSION

The temporal trends of organochlorine residues in herring gull eggs show that levels of PCBs, DDE, mirex, HCB and TCDD were much higher in the early 1970s than they are today. The half-lives calculated from these curves are similar to those found experimentally in young herring gulls (Clark *et al.*, 1987). The exception to these trends is the trend for dieldrin. In some cases (e.g. the Niagara River, Big Sister Island in Green Bay and Agawa Rock in Lake Superior), current levels do not differ appreciably from levels in the 1970s. The reason for this is unclear since its half-life (estimated from experimental studies) (Clark *et al.*, 1987) is shorter than those of mirex and DDE. This suggests that there could be continued inputs of dieldrin to the ecosystem.

The high levels of organochlorines in the 1970s were a consequence of the manufacture, use and discharge of these chemicals. As restrictions and bans were implemented in both Canada and the U.S., levels decreased. Despite these measures, organochlorines are still detected in herring gull eggs and in the 1980s levels equilibrated. This indicates that levels in the Great Lakes ecosystem have equilibrated. In addition to ongoing discharges from point sources, several factors are likely to be maintaining this equilibrium including long range atmospheric transportation and deposition, re-suspension of contaminated sediments, leachate from hazardous waste disposal sites, and continued run-off and volatilization from agricultural areas. Combustion is the most likely source of background dioxin and furan levels in the ecosystem.

3. DOUBLE-CRESTED CORMORANT

Double-crested cormorants first nested in the Great Lakes in the 1920s in eastern Lake Superior. By the late 1930s they had expanded their range and become established in all of the Great Lakes. By the late 1940s, they had become so numerous that they were deemed to be a competitor with the local commercial fishermen and control measures were introduced (Omand, 1947). As several feeding studies have shown, however, cormorants seldom take commercially important species of fish. The main diet of double-crested cormorants in the Great Lakes is alewife and rainbow smelt. From the 1950s through to the early mid-1970s, cormorant populations on the Great Lakes declined dramatically. This was initially because of the control program and subsequently because of DDE-induced eggshell thinning (Scharf and Shugart, 1981; Ludwig, 1984; Price and Weseloh, 1986; Weseloh et al., 1986, 1988). Volume II of this report contains a more detailed discussion of cormorant breeding populations and productivity.

Levels of organochlorine contaminants in cormorant eggs from the Great Lakes were first monitored in the late 1960s. Subsequently, it became apparent that the eggs were heavily contaminated with DDE, PCBs and mercury and that colony size, productivity and eggshell thickness were decreasing (Vermeer and Peakall 1977a,b; Postupalsky, 1978; Weseloh et al., 1983).

In the late 1970s, the situation began to improve as contaminant levels decreased and biological conditions improved. This pattern continued in the 1980s (Table 2). PCB data for cormorants are based on Aroclor 1254/1260 1:1 mixture standards and values cannot be compared with those for herring gulls. In addition, the sites and years in which eggs were collected are different. Herring gulls are the primary indicator species. Cormorants were simply not available for study at many sites during the 1960s and the 1970s. Population levels of cormorants are now nearly 10 times higher than they have been at any time in the recorded history of this bird on the Great Lakes.

3.1 LAKE ONTARIO

Data are available on eggs from four sites on Lake Ontario (three of which are located in eastern Lake Ontario) for 1972 - 1989. Since each site was sampled only once during this period, it is impossible to establish temporal trends at any one site. Data from Scotch Bonnet Island (1972) and Pigeon Island (1981) suggest that DDE levels have decreased and that PCB (Aroclor 1260) levels have not changed. There may be some geographical variation in contaminant levels in cormorant eggs from Lake Ontario and both DDE and PCB levels were higher in eggs from Little Galloo Island than in eggs from Pigeon Island in 1981.

3.2 LAKE ERIE

The data set of contaminant levels in cormorant eggs from Lake Erie is probably better than that from the Great Lakes. Table 2 shows data from Big Chicken and East Sister Islands. Cormorants nested on Big Chicken Island in the Western Basin until 1986 when they moved the short distance to East Sister Island. These data show that in 1989, DDE, PCBs and dieldrin decreased to approximately half or less of the levels in the 1970s. Levels of both mirex and HCBs have decreased since 1979.

3.3 LAKE HURON

Data are available on contaminants in cormorants eggs from Georgian Bay and the North Channel (Lake Huron) for 1970/1971 - 1989. There are samples from Wallis Rock on Georgian Bay from 1971, 1972 and 1973. Unfortunately, the sample sizes are too small to be conclusive. However, the sample size from the Blackbill Islands is adequate. Concentrations of DDE in eggs from this location decreased by nearly 40% between 1970 and 1971. From 1971 to 1989, all compounds measured decreased. For example, concentrations of PCBs decreased by 88% and concentrations of DDE decreased by 87%. Between 1971 and 1975, eggs from cormorant colonies in the North Channel were sampled more extensively than any other location in the Great Lakes. The North Channel is a relatively small water body and the colonies are reasonably close together, hence Table 2 shows concentrations in individual colonies as well as a "combined value", where sample sizes were adequate. The combined values show a 90% reduction in DDE levels from 1971 to 1989. Concentrations of PCBs (Aroclor 1260) decreased by 40% from 1971 to 1979 and by 91% to 1989.

TABLE 2. SUMMARY OF ORGANOCHLORINE LEVELS (PPM, WET WEIGHT) IN EGGS OF DOUBLE-CRESTED CORMORANTS

LAKE ONTARIO	1972	1981	1989
Scotch Bonnet Island			
PCBs (1260)	18.3		
DDE	9.4		
Dieldrin	0.27		
% Lipid	3.5		
Sample size (N)	7		
Pigeon Island			
PCBs (1260)		17.8	
PCBs (1254/1260)		20.7	
DDE		3.7	
Mirex		-	
Dieldrin		-	
% Lipid		4.2	
N		10	
Little Galloo Island			
PCBs (1260)		33.1	
PCBs (1254/1260)		37.9	
DDE		5.8	
Mirex		1.24	
Dieldrin		-	
% Lipid		4.2	
N		10	
Hamilton Harbour			
PCBs (1260)			9.9
PCBs (1254/1260)			20.1
DDE			3.86
Mirex			0.43
Dieldrin			0.16
% Lipid			4.60
N			1[*]

[*] 10 egg pool, 1 analysis

TABLE 2. CONTINUED

LAKE ERIE	1972	1979	1981	1983	1989
Big Chicken/East Sister Island					
PCBs (1260)	18.8	35.5	33.8	29.3	13.4
PCBs (1254/1260)	-	45.5	38.7	36.6	22.9
DDE	6.4	4.5	3.6	2.7	3.4
Mirex	-	0.11	0.05	0.05	0.07
HCB	0.007	0.05	0.04	0.03	0.02
Dieldrin	0.2	0.3	ND	0.3	0.06
% Lipid	8.3	4.2	4.1	4.7	4.53
N	18	10	10	1[*]	1[*]

[*] = 10 egg pool, 1 analysis

LAKE SUPERIOR	1983	1989
Gravel Island		
PCBs (1260)	12.9	13
PCBs (1254/1260)	2.5	4.1
DDE	0.03	0.05
HCB	0.03	0.02
Dieldrin	0.4	0.13
% Lipid	4.7	4.4
N	1[*]	1[*]

[*] 10 egg pool, 1 analysis

TABLE 2. CONTINUED

GEORGIAN BAY	**1970**	**1971**	**1972**	**1973**	**1989**
Wallis Rock					
PCBs (1260)	41.8	24.9	17.4		
PCBs (1254/1260)	-	-	-		
DDE	15.9	15.6	12.4		
Mirex	-	-	-		
HCB	0.50	0.12	0.02		
Dieldrin	0.47	0.12	0.53		
% Lipid	3.9	7.7	3.2		
N	2	3	1		
Blackbill Islands					
PCBs (1260)	20.5	22.8		5.2	
PCBs (1254/1260)	-	-		9.8	
DDE	24.9	15.6		2.0	
Mirex	-	-		0.04	
HCB	ND	0.21'		0.01	
Dieldrin	0.7	0.5		0.04	
% Lipid	4.5	5.5		4.6	
N	7	8		1''	

' N = 6

''10 egg pool, 1 analysis

Bustard Island					
PCBs (1260)		23.0			
PCBs (1254/1260)		-			
DDE		16.4			
Mirex		-			
HCB		0.01			
Dieldrin		0.3			
% Lipid		8.7			
N		3			

TABLE 2. CONTINUED

NORTH CHANNEL	1971	1972	1973	1975	1979	1989
Gull Rock						
PCBs (1260)	24.8		17.3			
PCBs (1254/1260)	-		22.3			
DDE	14.5		3.8			
HCB	0.01		0.01			
Dieldrin	0.41		0.23			
% Lipid	7.5		4.1			
N	9		1			
Doucet Rock						
PCBs (1260)	31.9	25.6		10.1		
PCBs (1254/1260)	-	-		11.9		
DDE	17.8	15.2		3.3		
HCB	0.04	0.01		0.01		
Dieldrin	0.6	0.5		0.2		
% Lipid	5.4	7.4		0.7		
N	7	2		1		
Africa Rock						
PCBs (1260)		28.3	9.9	17.8		
PCBs (1254/1260)		-	11.2	20.5		
DDE		15.4	7.1	2.4		
Mirex		-	ND	0.15*		
HCB		0.02	0.01	0.04		
Dieldrin		0.49	0.53	0.28		
% Lipid		3.6	3.8	4.5		
N		1	2	9		
* N = 8						
Talon Rock						
PCBs (1260)	24.8	10.3				
PCBs (1254/1260)	-	-				
DDE	17.7	5.12				
HCB	0.01	0.01				
Dieldrin	0.39	0.01				
% Lipid	3.8	6.1				
N	3	1				

TABLE 2. CONTINUED

	1971	1972	1973	1975	1979	1989
West Island						
PCBs (1260)						2.78
PCBs (1254/1260)						6.20
DDE						1.95
Mirex						0.01
HCB						0.02
Dieldrin						0.05
% Lipid						4.33
N						1[*]

[*] 10 egg pool, 1 analysis

	1971	1972	1973	1975	1979	1989
Gull, Doucet, Africa and Talon Rocks and West Island (combined)[1]						
PCBs (1260)	29.8	23.7		11.8	17.8	2.78
PCBs (1254/1260)	-	-		14.2	20.5	6.20
DDE	17.7	13.8		5.33	2.4	1.95
Mirex	-	-		-	0.15[*]	0.01
HCB	0.03	0.01		0.01	0.04	0.02
Dieldrin	0.16	0.39		0.82	0.28	0.05
% Lipid	4.9	7.3		3.1	4.5	4.33
N	10	12		4	9	1[**]

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1. Combined values are a weighted mean based on the number of eggs.

[*] N = 8

[**] 10 egg pool, 1 analysis

Source: D.V. Weseloh, Canadian Wildlife Service, unpublished data

3.4 LAKE SUPERIOR

Less than 5% of the Great Lakes cormorant population breeds on Lake Superior, and only minimal sampling has been conducted there. Table 2 shows data based on pooled samples from the Gravel Island colony, near Thunder Bay, for 1983 and 1989.

3.5 DISCUSSION

In the last twenty years, Great Lakes cormorants have experienced tremendous changes in population numbers. This coincided with changes in levels of DDT and its metabolites in their eggs. This species, and the black-crowned night heron are the most sensitive to DDT (see Volume II). Trends in contaminant levels are similar to those in herring gull eggs.

4. CASPIAN TERN

The Caspian tern is distributed throughout the world in disjunct populations. Approximately one-third of the global populations nests in North America (Martin, 1978 as cited in Struger and Weseloh, 1985). A large portion of the North American population breeds along the northern shores of Lake Michigan, Georgian Bay, the North Channel section of Lake Huron and in Lake Ontario (Ludwig, 1979). The Caspian tern resides in the Great Lakes for approximately six months of the year, from May to October. It is a piscivorous species. Figure 1 shows the location of the colonies sampled in the Great Lakes basin. At each site, 10 eggs were randomly collected. Table 3 shows the levels of organochlorines found in the samples.

TABLE 3. ORGANOCHLORINE RESIDUES (PPM, MEAN WET WEIGHT +/- STANDARD DEVIATION) IN EGGS OF CASPIAN TERNS FROM THE GREAT LAKES, 1980 and 1981

	N	DDE	Mirex	PCBs	HCB
Lake Huron[1]					
South Limestone Is.	10	3.7+/-1.3 B[2]	0.31+/-.15 B	26.0+/-9.7 AB	0.03+/-0.01 A
The Cousins Is.	10	4.7+/-1.9 B	0.07+/-.02 B	30.9+/-9.3 AB	0.05+/-0.03 A
Halfmoon Is.	9	3.3+/-1.1 B	0.09+/-.06 B	18.5+/-6.8 A	0.04+/-0.02[3] A
Lake Michigan[1]					
Gravelly Is.	10	8.8+/-5.0 A	0.06+/-.01 B	36.2+/-9.2 B	0.04+/-0.02 A
Hat Is.	9	5.6+/-2.2 B	0.05+/-.03 B	27.8+/-8.9 AB	0.04+/-0.03 A
Isle aux Galets	9	4.6+/-1.2 B	0.04+/-.01 B	24.7+/-6.2 AB	0.04+/-0.03 A
Lake Ontario[1]					
Pigeon Is.	8	5.2+/-1.6 B	1.57+/-.53 A	39.3+/-17.8 B	0.06+/-0.04 A

1. Eggs from Lake Huron and Lake Michigan collected in 1980; eggs from Lake Ontario in 1981.
2. For each colony, residue means that do not share the same letters are significantly different ($P<0.05$) from each other.
3. N = 8.

Source: Struger, J. and D.V. Weseloh, 1985.

In 1980/1, PCB levels ranged from 39.3 ppm in the eggs from Pigeon Island, Lake Ontario to 18.5 ppm eggs from Halfmoon Island in Lake Huron. Of the three colonies on Lake Michigan, Gravelly Island had the highest PCB levels (36.2 ppm, compared to 27.8 and 24.7 ppm). The Cousins Island colony on Lake Huron had a high concentration (30.9 ppm).

DDE residues were highest in eggs from the Gravelly Island colony. Mirex levels were significantly higher in eggs from the Pigeon Island, Lake Ontario colony than in eggs from any of the other lakes ($p < 0.05$) at 1.57 ppm. The lowest mirex levels (mean 0.04 ppm) were found at Isle aux Galets, Lake Michigan. HCB residues showed no significant geographical variation and ranged from 0.06 at Pigeon Island, Lake Ontario to 0.03 ppm at Lake Huron's South Limestone Island colony.

Table 3 shows that Caspian tern eggs from Lakes Ontario and Michigan are more heavily contaminated than eggs from Lake Huron. This is consistent with findings in other wildlife species.

Comparisons between current and historical contaminant levels in Caspian terns (Struger and Weseloh, 1985) are shown in Table 4. There are significant differences in concentrations of DDE and PCBs in eggs from Lake Ontario collected between 1972 and 1981. In most cases (except PCBs in eggs from Lake Huron) organochlorines were present at lower levels in 1980 and 1981 than in earlier years. Between 1976 and 1980 there were no significant changes in levels of DDE, mirex and PCBs at South Limestone Island, Lake Huron (t test, $p > 0.05$).

TABLE 4. COMPARISON BETWEEN HISTORICAL AND CURRENT ORGANOCHLORINE RESIDUES (PPM, MEAN WET WEIGHT +/-STANDARD DEVIATION) IN EGGS OF CASPIAN TERNS FROM LAKE HURON AND LAKE ONTARIO

	N	DDE	Mirex	PCBs
Lake Huron				
South Limestone Island				
1976[1]	10	7.8+/-10.0	0.51+/-.65	21.6+/-12.9
1980	10	3.7+/- 1.3	0.31+/-.15	22.7+/- 9.7
Lake Ontario				
Pigeon Island				
1972[1]	4	13.8+/- 4.9	N.A.[3]	81.2+/-36.0
1981	8	5.2+/- 1.6[2]	1.57+/-.53	39.3+/-17.8[2]

1. Data are from Martin (1978).
2. Significant between year difference 1972 vs. 1981 (P< or = 0.05)

N.A. = not analyzed.

Source: Struger, J. and D.V. Weseloh, 1985.

5. COMMON TERN

Eggs were collected from four sites on Lakes Ontario, Erie and Huron and the Detroit River in 1981 and comparisons were made to earlier collections (Weseloh *et al.*, 1989). The data are shown in Tables 5 and 6.

In 1981, tern eggs from Lake Ontario were more contaminated than those from the other three colonies (Figure 5). Levels of DDE, PCBs and mirex were significantly higher ($p \leq 0.05$) in tern eggs from Lake Ontario than in eggs from most other sites. The Lake Ontario colony had the highest concentrations of PCBs followed by the Detroit River colony. The lowest concentration of DDE (0.95 ppm) was found in the eggs from Lake Erie and the lowest concentrations of PCBs, dieldrin and mirex were found in the Lake Huron colony.

Table 6 contains a comparison between 1981 and earlier samples. It shows that levels of DDE and PCBs decreased at all sites. These trends are consistent with trends in other avian species from the Great Lakes.

TABLE 5. GEOMETRIC MEAN CONCENTRATION (PPM, WET WEIGHT) OF ORGANOCHLORINE RESIDUES IN EGGS OF COMMON TERNS, 1981

Location	DDE	PCBs	HCB	Dieldrin	Mirex
Lake Ontario					
Leslie St. Spit	2.46 A[1]	10.40 A[1]	—	0.14 A[2]	0.71 A[2]
Lake Huron					
N. Limestone Island	1.77 A	2.91 C	—	0.11 A	0.09 B
Detroit R.					
Fighting Island	1.02 B	8.24 A	0.08	—	—
Lake Erie					
Port Colborne	0.95 B	4.76 B	—	—	—

1. One-way analysis of variance and the Tukey's multiple comparison method, *alpha* = 0.05. Means not sharing the same letter are significantly different.
2. T-test, *alpha* = 0.05. Means not sharing the same letter are significantly different.

Source: D.V. Weseloh et al, 1989.

TABLE 6. COMPARISON BETWEEN HISTORICAL AND 1981 RESIDUE LEVELS (PPM, GEOMETRIC MEAN WET WEIGHT) IN EGGS OF COMMON TERNS FROM LAKE ONTARIO, LAKE ERIE, DETROIT RIVER AND LAKE HURON

Location	N	Year	DDE	PCB[1]	Source[2]
Lake Ontario					
Mugg's Island	10	1972[3]	NR[4]	52.8	1
Mugg's Island	8	1972[3]	13.0	65.4	2
Leslie St. Spit	10	1981	2.5	10.4	3
Lake Erie					
Port Colborne	8	1971[3]	10.9	78.8	2
Port Colborne	4	1972[3]	5.4	37.8	2
Port Colborne	10	1981	0.95	4.8	3
Detroit River					
Fighting Island	5	1972[3]	NR	31.3	1
Fighting Island	10	1981	1.0	8.2	3
Lake Huron					
Lake Huron	8	1969-73[3]	4.3	17.8	4
N. Limestone Island	10	1981	1.8	2.9	3

1. All PCB values presented in this table were measured as Aroclor 1260.
2. 1: Gilbertson *et al.*, 1976; 2: Morris *et al.*, 1976; 3: Weseloh *et al.*, 1981; 4: Gilbertson and Reynolds 1974.
3. Dry weight concentrations divided by 4.6 to convert to wet weight values.
4. NR = Not Reported.

Source: D.V. Weseloh *et al.*, 1989.

6. BLACK-CROWNED NIGHT-HERON

Contaminant levels in eggs of the black-crowned night-heron were determined for colonies on Lakes Ontario, Erie, Huron and the St. Clair and Niagara Rivers (Weseloh *et al.*, unpublished). Egg collections took place in 1973, 1976, 1982 and/or 1986. Table 7 shows the mean organochlorine levels for 1982 samples at the five sites. Patterns are discernable for some contaminants. Concentrations of DDE, dieldrin and mirex were noticeably lower in eggs from the Middle Island site in Lake Erie compared to those from Pigeon Island in Lake Ontario. The high mirex levels at the Lake Ontario (1.0 and 0.84 ppm) and Niagara River (0.75 ppm) sites, compared to those from Lake Erie (0.03 ppm) are consistent with the spatial distribution of mirex concentrations in other species. There were no apparent trends in PCBs and HCB in night-heron eggs.

Table 8 shows a historical comparison of organochlorine residues in night-heron eggs from the lower Great Lakes for 1976, 1982 and/or 1986. Levels decreased at all three sites. There are not sufficient data to deduce whether changes in contaminant residues are occurring in this species.

TABLE 7. MEAN VALUES (ARITHMETIC MEAN, PPM, WET WEIGHT) AND RANGE (IN BRACKETS WHERE APPLICABLE) OF ORGANOCHLORINE RESIDUES IN BLACK-CROWNED NIGHT-HERON EGGS FROM GREAT LAKES COLONIES, 1982

	Lake Erie	Lake Ontario		Niagara R.	Lake Huron
Chemical	Middle I.	Pigeon I.	Little Galloo I.		Chantry I.
DDE	1.7	4.8	4.1	4.8	4.0
	(0.85-4.0)	(1.6-9.9)			
Dieldrin	0.11	0.28	0.24	0.31	0.11
	(0.04-0.32)	(0.03-1.8)			
Mirex	0.03	1.0	0.84	0.75	0.19
	(0.01-0.05)	(0.19-2.1)			
HCB	0.03	0.04	0.05	0.06	0.04
	(0.010-0.053)	(0.018-0.10)			
PCB	28.7	24.4	18.9	18.9	19.2
	(8.6-52.4)	(9.2-44.0)			

Note:Values without ranges are single analysis of 10-12 egg pools

Source: D.V. Weseloh *et al.*, Canadian Wildlife Service unpublished report, 1982.

TABLE 8. HISTORICAL COMPARISON OF ORGANOCHLORINE RESIDUES (ARITHMETIC MEAN, PPM, WET WEIGHT) IN BLACK-CROWNED NIGHT-HERON EGGS FROM THE LOWER GREAT LAKES COLONIES, 1976-1986

	Lake Erie		**Lake Ontario**		**Niagara R.**		**St. Clair R.**
	Middle I.		Pigeon I.				Walpole I.
Chemical	1982	1986	1976[1]	1982	1982	1986	1986
DDE	1.7	0.76	6.1	4.8	4.8	3.3	1.8
Dieldrin	0.11	0.03	0.27	0.28	0.31	0.22	0.07
Mirex	0.03	0.01	0.80	1.0	0.75	0.90	0.11
HCB	0.03	0.01	0.07	0.04	0.06	0.06	0.01
PCBs	28.7	13.2	26	24.4	18.9	33.4	8.7
% Lipid	5.7	5.1	-	6.0	5.5	5.5	5.8
N[2]	10	1	18	12	1	1	1

1. Price, 1977.
2. Samples of N = 1 are 10-12 egg pools, single analysis.

Source: D.V. Weseloh, unpublished report 1982, and unpublished data.

7. BALD EAGLE

The bald eagle population in the Great Lakes region was originally part of a continuous population that extended from the east coast of North America to the prairies. Today, the population is disjointed and the eagles have been extirpated from large areas. Bald eagles return to the same nesting site year after year and those nesting in the lower lakes are vulnerable to environmental contamination. Those breeding in the less contaminated upper lakes may be exposed to contaminants year round by migrating to contaminated areas outside their breeding season. The effects of toxic chemicals on the reproductive success of the bald eagle are discussed in Volume II, Part 2 of this report.

Systematic egg collection has not been possible because of the endangered status of bald eagles in Canada and the U.S. Data on contaminant burdens have been obtained by analyzing eggs that failed to hatch (addled eggs). The eggs that have been recently examined were addled, fertile and showed no obvious deformities when intact embryos were found (IJC, 1987). A map showing the distribution of shoreline nests from which eggs have been collected and the concentrations of DDE, PCBs and dieldrin in eggs from those nests is shown in Figure 24 (IJC, 1987). Levels of these three chemicals are equal to or higher than those in herring gull eggs collected from the same general area. Some bald eagles in the Great Lakes feed on herring gulls as part of their diet. This is a very highly contaminated food source. They also eat large fish, turtles, waterfowl and muskrats.

Data on levels of PCBs, DDE and dieldrin in bald eagle eggs collected since 1969 are shown in Figure 25. Eggs were collected from sites on Lakes Superior, Erie, Huron and Michigan. These data are inadequate for any detailed temporal or geographic analysis. However the level of DDE (3 ppm) considered critical for maintaining a stable population (Wiemeyer, *et al.*, 1984) was exceeded in all eggs sampled. Similarly, the levels of PCBs that would result in "a marked effect on embryo survival in some bird species" was exceeded in almost all eggs sampled (Peakall, 1987). The relationship between toxicant levels and eagle reproduction is discussed in more detail in Volume II.

Recently (1986-1988), twenty-two eggs taken from shoreline and inland bald eagle nests on the U.S. side of the Great Lakes have been analyzed by the U.S. Fish and Wildlife Service, with the cooperation of the Michigan and Ohio Departments of Natural Resources. The results are reported in Table 9. In aggregate, levels of DDE, PCBs and dieldrin are significantly higher in addled eggs from shoreline nests than from inland ones. Nine eggs collected from shoreline sites between 1986 and 1988 had PCB values ranging from 8.6 to 118 ppm (median value 43 ppm) and DDE values ranging from 2.3 to 35 ppm (median value 10 ppm). The corresponding values for ten inland eggs were 2.4 to 29 (median value 7.8) and 0.48 to 16 (median 1.5 ppm). At present, there are insufficient data to establish any temporal trends.

Congener specific analyses for PCBs have been conducted on two eggs. The TCDD equivalents of these eggs have been calculated by multiplying the concentration of each individual congener by its activity relative to 2,3,7,8-TCDD and summing the results (Casterline *et al.*, 1983). On this basis, TCDD equivalent values of 21.4 ppb and 30.9 ppb were obtained. The relationship of TCDD equivalents to reproductive effects in fish-eating birds is discussed in Volume II, Part 2.

Addled bald eagle eggs from Great Lakes shoreline nests contain significantly higher organochlorine residues (PCBs, DDE, and dieldrin) than inland breeding areas within the Great Lakes basin.

TABLE 9. CONCENTRATIONS OF ORGANOCHLORINES (PPM, FRESH WEIGHT) IN EGGS[1] FROM BALD EAGLE NESTS IN THE GREAT LAKES BASIN, 1986-1988

Year	Site	PCB[2]	DDE	Dieldrin	% lipid (Wet Weight)
Shoreline					
1986	Lake Michigan (Big Bay de Noc)	51 60	26 35	1.9 2.22	6.7 5.9
1986	Lake Erie	43	10	0.69	5.6
1986	Lake Huron (Thunder Bay)	96 118	38 45	2.2 2.5	6.8 12.9
1986	Lake Superior (Whitefish Bay)	13	9.5	0.51	3.8
1987	Lake Erie	8.6	2.7	0.25	5.6
1988	Lake Superior (In Michigan)	14	2.4	0.18	5.3
1988	Lake Erie (Sandusky Bay)	25	2.3	0.60	5.3
Inland					
1986	Lake Michigan (Menominee River)	28 29	16 16	0.9 0.9	5.2 6.2
1986	Michigan[1]	12 14	5.2 6.2	0.24 0.26	3.8 7.0[3]
1987	Ohio	6.3	1.3	0.9	11[4]
1987	[1]Michigan (Menominee drainage basin)	8.2 7.8 2.0 4.0	0.60 1.4 1.1 2.1	0.09 0.13 0.08 0.40	4.2 8.5 5.1 4.4
1988	Michigan	13	2.7	0.06	5.0
	(lower peninsula) (Michigan/Wisconsin border)	3.4 2.4	0.68 0.48	0.09 0.06	3.5 3.6
1988	Ohio	5.6	1.5	0.07	4.8

Note: A ( ) denotes eggs taken from the same clutch. See Figure 26 for shoreline site locations.

1. These are measurements for single eggs.
2. PCB concentrations based on analysis using Aroclor mixtures.
3. Egg was dehydrated.
4. Lipid content outside of observed range of 3.5-8.5%.

Source: D. Best, U.S. Fish and Wildlife Service, unpublished data.

8. MINK

Mink are widely distributed in the Great Lakes basin. They are carnivorous, feeding on mammals, fish, birds and crayfish. The first evidence that suggested that wild mink could be experiencing reproductive failure was that ranch mink fed on fish from the Great Lakes exhibited reproductive difficulties (Hartsough, 1965). Subsequent detailed toxicological studies showed that PCBs and possibly dioxins were responsible but that mink were comparatively insensitive to DDT (see Volume II). Recent studies have shown evidence of high contaminant levels in wild mink (Weseloh, unpublished; Proulx et al, 1987). Table 10 shows the PCB and DDE residues in mink from five regions of Lake Ontario. Distance from shore is an important factor because animals which are farther away from the lakeshore may not feed exclusively on Great Lakes fish. As expected, mink sampled from inland sites often had lower organochlorine levels.

TABLE 10. PCB AND DDE RESIDUES (PPM, LIPID WEIGHT) IN POOLED SAMPLES OF MINK FROM FIVE REGIONS OF LAKE ONTARIO, WINTERS 1981/82, 1982/83

Location	d(km)		N	PCBs	DDE	PCBs/DDE
Prince Edward	>8	L	8	3.20	0.80	4.0
St. Lawrence	0-3	L	10	56.70*	2.22	25.5
River		W	3	6.70	0.28	23.9
	3-8	L	10	6.80	0.40	17.0
	>8	L	8	4.30	0.43	10.0
Flamborough	>8	L	10	8.80	1.25	7.0
Puslinch	>8	L	10	6.20	1.47	4.2
Whitby-	0-3	L	5	20.60*	2.60	7.9
Cobourg	3-8	L	5	27.60*	6.40*	4.3
	>8	L	10	46.70*	3.33	14.0
		W	4	19.40*	3.33	5.8

Note: d(km) = distance from the shore in kilometres
N= number of carcasses in the pooled sample
L= liver
W= whole body
* Significantly different from remaining PCB/DDE samples

Source: D.V. Weseloh, Canadian Wildlife Service, unpublished data

Liver PCB concentrations ranged from 3.20 ppm in animals from inland Prince Edward County to 56.70 ppm in animals along the St. Lawrence River on a lipid weight basis. Higher concentrations were observed in the mink from the Whitby - Cobourg area. Liver DDE residues ranged from 0.40 ppm along the St. Lawrence River to 6.40 ppm in the Whitby - Cobourg area. DDE levels in the Whitby - Cobourg area were significantly higher than elsewhere.

PCB and DDE residue data in mink from five regions on the north shore of Lake Erie are shown in Table 11. Carcasses were obtained from trappers. Unfortunately, the distance of each animal from the lakeshore was not accurately known. One of the five regions, Tuscarora Township, is inland from Lake Erie. Geometric mean concentrations of PCBs ranged from 1.81 to 29.17 ppm for the five regions. PCB levels of whole animal homogenates (calculated on a lipid weight basis) are representative of adipose tissue accumulation. PCB residues in wild mink from Walsingham, Dunn-Rainham and Mersea Townships were higher than levels in experimental animals (10 to 43 ppm in adipose tissue) which caused significantly reduced reproduction and 100% kit mortality in three weeks (Proulx *et al.*, 1987). It is likely that

TABLE 11. PCB AND DDE RESIDUES (PPM, LIPID WEIGHT) IN MINK BODY HOMOGENATES FROM FIVE REGIONS OF LAKE ERIE COLLECTED IN THE WINTERS OF 1978 AND 1979

	Mersea Twp.	**Dunn-Rainham Twp.**	**Walsingham Twp.**	**Wainfleet Twp.**	**Tuscarora Twp. (Inland)**
PCBs	29.17 (15)[1]	26.12 (9)	10.74 (11)	6.08 (13)	1.81 (5)
	4.1-102.5[2]	7.8-80.1	2.3-35.9	1.4-23.0	0.8-2.9
	17.22-49.42[3]	13.36-51.05	6.0-19.22	3.82-9.67	0.65-5.06
DDE	4.83 (15)	2.08 (9)	5.48 (11)	1.16 (13)	1.62 (5)
	1.67-13.08	1.29-6.52	0.80-33.7	0.26-4.64	0.27-12.7
	3.39-6.88	1.35-3.23	2.59-11.62	0.73-1.85	0.29-8.89
RATIO PCB/DDE	6.00	12.56	1.96	5.24	1.11

1. Geometric mean (number of carcasses with detectable levels)
2. Range of individual values
3. Confidence interval limits of the logarithmic mean

Source: G. Proulx et al, 1987

these wild populations experienced reduced reproductive success as a result of exposure to PCBs. The range of PCB residue levels in mink from Tuscarora Township is considerably less than the ranges in mink from the other regions. The variation in PCB levels between regions suggests that either they had different diets or that the degree of PCB contamination varied. Mink are less sensitive to DDT and its metabolites, and levels of DDE found in these populations are unlikely to be toxic to mink.

9. COMMON SNAPPING TURTLE

The common snapping turtle (*Chelydra serpentina*) accumulates organochlorines mainly in its fat, liver and eggs due to the high lipid content of these tissues. While little is known about the biological effects of toxic chemicals on this species, a significantly higher incidence of embryonic abnormalities has been found in some lakeshore population compared to an inland population (Volume II). The snapping turtle is a long-lived and omnivorous animal, and occupies a home range of approximately five hectares. It is found in a variety of Great Lakes wetlands habitats. For these reasons, the snapping turtle may serve as a useful indicator of environmental contaminant levels and more particularly as an indicator of local contaminant discharge (Struger *et al.*, unpublished).

Snapping turtle eggs have been collected from wetlands in Ontario and Quebec during three periods: 1981/84, 1986/87 and 1988/89 (Figure 27). Snapping turtle eggs were first collected and analyzed from sites on the Great Lakes shoreline in 1981 from nests at Big Creek Marsh and from a site outside the basin, in Algonquin Park. In 1984, eggs were taken from eight sites on Lake St. Clair, Lake Ontario and the St. Lawrence River. The results from selected sites are summarized in Table 12. PCBs, DDT, DDE, mirex and HCB were detected in eggs from at least one clutch at all sites. PCBs were found in all of the samples. In descending order of percentage occurrence, DDE, oxychlordane, dieldrin, HCB and mirex, cis-chlordane, heptachlor epoxide, trans-nonachlor, DDD, gamma-chlordane, DDT, beta-HCH, endrin and alpha-HCH were detected. Chlorobenzenes were found in some samples at trace levels. The highest levels of PCBs, DDE, mirex, dieldrin and oxychlordane were found in eggs from Hamilton Harbour. Concentrations of these chemicals were significantly higher than in eggs from all other locations. Eggs from Lake St. Clair had significantly higher levels of HCB.

The very low or non-detectable levels in snapping turtle eggs collected from Algonquin Park are indicative of background levels. These levels can probably be attributed to long-range atmospheric transport.

Snapping turtle eggs were collected in 1986 and 1987 from Lakes Ontario and Erie and analyzed for the presence of six PCB congeners and four organochlorine pesticides (Table 13).

TABLE 12. MEAN ORGANOCHLORINE CONCENTRATIONS (PPB, WET WEIGHT) IN SNAPPING TURTLE EGGS FROM GREAT LAKES - ST. LAWRENCE WETLANDS, 1981 AND 1984

Site	Year	% Lipid	N[1]	DDE	HCB	Mirex	PCBs[2]
Hamilton Harbour	1984	6.0	5	284+/-110	22+/-17	86+/-56	8590+/-4770
Rondeau Prov. Park	1984	4.9	5	42+/-31	3+/-2	5.0+/-3.5	2318+/-1482
Lynde Shores Conservation Area	1984	5.0	5	90+/138	3.4+/-4.6	39.2+/-51.6	2312+/-3546
Lake St. Clair	1984	5.8	5	122+/-46	57+/-57	5+/-5	2576+/-1304
St. Lawrence River	1984	5.9	5	56+/-72	11.2+/-18.1	26.0+/-16.7	1694+/-930
Big Creek Marsh	1981	7.1	5	102+/-84	3.6+/-1.5	9.0+/-6.5	2142+/-2110
Algonquin Park	1981	5.7	6	12+/-10	0.61+/-0.51	2.5+/-2.7	272+/-105

1. N refers to number of clutches. Eggs from each clutch were pooled and analyzed for residues. In 1981, 5 eggs were taken from each nest while in 1984, 10 eggs were taken.
2. Concentrations are based on Aroclor 1254/1260 1:1 mixture.

Source: J. Struger et al, Canadian Wildlife Service unpublished report, 1988.

In 1986, contaminant concentrations in eggs from Cootes Paradise and Lynde Creek were not significantly different except for p,p'-DDE levels which were significantly higher at Cootes Paradise. Those two populations had significantly higher concentrations for all contaminants except p,p'-DDE for which Lynde Creek and Big Creek Marsh eggs were not significantly different. Big Creek Marsh eggs were moderately contaminated among the five populations. Cranberry Marsh eggs had levels of HCB and PCB which were not significantly different from those in Big Creek Marsh eggs and levels of chlordane, nonachlor and p,p'-DDE which were not significantly different from those in Algonquin Park eggs. Eggs from Algonquin Park contained the lowest levels of all chemicals measured (Table 13).

In 1987, eggs collected in Cootes Paradise and Cranberry Marsh in 1987 had significantly lower PCB, a-chlordane and t-nonachlor and significantly higher p,p'-DDE concentrations compared to eggs from the same sites in 1986. Levels of hexachlorobenzene significantly decreased in eggs at Cranberry Marsh from 1986 to 1987; at Cootes Paradise they were not significantly different between years (Table 13).

The 1986/87 data coincide with earlier 1981/84 data in that contaminant levels at Cootes Paradise/Hamilton Harbour were significantly higher than most sites sampled. In 1986/87, however, Lynde Creek was equally or more contaminated. This was not indicated in the earlier study.

TABLE 13. MEAN ORGANOCHLORINE CONCENTRATIONS (PPB, WET WEIGHT+/-STANDARD DEVIATION) IN SNAPPING TURTLE EGGS FROM LAKE ONTARIO AND LAKE ERIE POPULATIONS IN 1986 AND 1987

Site	Year	N[1]	Hexachlorobenzene	alpha-Chlordane	p,p'-DDE	Total PCBs[2]
Cootes Paradise/ Hamilton Harbour	1986	21	17.3+/-2.5 A	76.7+/-11.5 A	131.0+/-43.5 A	1618.0+/186.8 A
	1987	16	12.1+/-2.1 A	24.0+/-5.3 A	135.0+/-31.9 A	947.0+/-167.6 A
Lynde Creek	1986	4	16.8+/-5.5 A	111.6+/-33.5 A	24.1+/-9.4 B	2708.4+/-1119.1 A
Cranberry Marsh	1986	18	3.4+/-0.6 B	21.1+/-5.4 C	2.4+/-0.6 C	605.0+/-171.7 B
	1987	12	1.1+/-0.1 B	0.7+/-0.4 B	85.2+/-55.3 B	257.2+/-62.7 B
Big Creek Marsh (L. Erie)	1986	5	3.1+/-1.5 B	2.1+/-0.8 B	69.8+/-9.9 A	689.9+/-124.3 B
Algonquin Park	1986	15	1.3+/-0.2 C	ND	2.0+/-0.5 C	76.1+/-13.5 C

1. N refers to the number of clutches. Five eggs were collected from each clutch, pooled and analyzed for residues.
2. Total PCBs = sum concentrations of PCB congeners found in eggs

Note: Letters refer to significant differences between sites for each year.
ND = not detected
Source: C. Bishop, Canadian Wildlife Service, unpublished data

Concentrations of Aroclor 1254:1260 PCB, DDE and mirex in 1988 were notable at Lynde Creek and Hamilton Harbour because they were considerably higher than in any other year. Comparing sites within 1988 (Table 14), DDE and PCB levels at Hamilton Harbour were significantly higher than at Lynde Creek. Lynde Creek had levels statistically higher than at Cranberry and Algonquin for PCBs, DDE and mirex. All three contaminants occurred at significantly higher levels in Cranberry Marsh eggs than in Algonquin Park. Levels of dioxins and furans were substantially higher at the Lake Ontario sites.

In 1989, snapping turtle eggs were collected from eleven sites. Comparing DDE, mirex and Aroclor 1254:1260 PCB residues, Lake Ontario eggs were most contaminated relative to eggs from Lake Erie, the St. Lawrence River and Algonquin Park (Table 14). In specific populations in

Lake Ontario such as those in Cootes Paradise/Hamilton Harbour, and Lynde Creek, eggs were substantially more contaminated with PCBs than eggs from elsewhere.

For sites with more than one clutch sampled, statistical analysis indicated that DDE levels at Hamilton Harbour were significantly higher than all other sites. Eggs from Fraser Point were significantly more contaminated with DDE than all sites except Hamilton Harbour. DDE levels at Toronto Harbour were significantly higher than at Cranberry Marsh, Lake Ontario and Big Creek Marsh and Rondeau Provincial Park, Lake Erie. Those latter three sites had significantly higher levels than Algonquin Park and Thurso. Among sites which had only one clutch sampled, the DDE levels at Lynde Creek were most similar to those at Fraser Point while levels from Boucherville were similar to those at Algonquin Park (Table 14).

Mirex levels were highest in eggs from Lake Ontario and lowest in eggs from Lake Erie and sites unconnected to Lake Ontario. Mirex levels at Hamilton, Toronto, and Cranberry Marsh were not significantly different but were statistically higher than all other sites. Mirex concentration in the one clutch of Lynde Creek eggs were highest among all samples. Levels of mirex in eggs from the Trent River and Fraser Point were similar but significantly higher than those from both Lake Erie sites, Algonquin Park, and Thurso (Table 14).

PCB levels in 1989 showed geographic similarities as in previous years, with Hamilton Harbour having significantly higher levels than all other sites. Toronto Harbour and Fraser Point PCB levels were not statistically different but were significantly higher than the remaining sites. Rondeau Park, Trent River and Cranberry Marsh PCB levels were not significantly different. Big Creek Marsh eggs had statistically higher levels than only Thurso and Algonquin Park eggs (Table 14).

Temporal trends can be examined for five populations which were sampled in 1984, and subsequently sampled in 1988 and/or 1989. These five populations were: Algonquin Park, Lynde Creek, Cranberry Marsh, Hamilton Harbour, and Rondeau Provincial Park. Mirex and DDE contamination in snapping turtle eggs compared between 1984 and 1989 had not declined markedly at any site except Hamilton Harbour and in some cases levels increased. In 1988, levels of DDE were 100% higher than in 1984 and in 1989 at Lynde Creek, Hamilton, and Algonquin. Mirex levels had also

TABLE 14. MEAN ORGANOCHLORINE CONCENTRATIONS (PPB, WET WEIGHT) IN SNAPPING TURTLE EGGS FROM GREAT LAKES AND ST. LAWRENCE RIVER POPULATIONS, 1988 AND 1989

Site	N[1]	p,p'-DDE	Mirex	PCBs[2]
1988				
Algonquin Park	8	8.0+/-6.4 D	0.5+/-0.6 C	68.4+/-61.0 D
Cootes Paradise/ Hamilton Harbour (Lake Ontario)	7	864.0+/-463.3 A	110.8+/-23.8 A	10172.5+/-1928.9 A
Cranberry Marsh (Lake Ontario)	8	80.9+/-78.3 C	25.8+/-28.0 B	979.4+/-1113.8 C
Lynde Creek (Lake Ontario)	9	471.6+/-294.1 B	142.8+/-57.0 A	4791.6+/-1708 B
1989				
Algonquin Park	9	1.8+/-1.6 F	0.1+/-0.1	28+/-15 F
Cootes Paradise (Lake Ontario)	7	311.0+/-154.0 A	44.0+/-27.0 A	4900+/-2020 A
Toronto Harbour (Lake Ontario)	4	75.5+/-31.0	47.0/-20.7	3160+/-1040 B
Cranberry Marsh (Lake Ontario)	7	59.9+/-45.5 D	33.1+/-3.8 A	1250+/-1240 C
Lynde Creek (Lake Ontario)	1	202.8	118.6	5128
Trenton (Lake Ontario)	7	53.9+/-58.0 D	21.0+/-27.0	1430+/-1570 C
Fraser Point (St. Lawrence)	7	218.0+/-24.0 B	21.0+/-15.0	3390+/-2580 B
Boucherville (St. Lawrence)	1	3.6	1.4	437.7
Big Creek Marsh (Lake Erie)	7	43.9+/-28.0 D	1.4+/-0.68 C	754+/-486 D
Rondeau Prov. Pk. (Lake Erie)	7	36.9+/-24.4 D	1.9+/-1.3 C	1420+/-910 C
Thurso (Ottawa River)	7	6.9+/-5.8 E	2.1+/-2.7 C	275+/-1140 E

1. N refers to the number of clutches. Five eggs were collected from each clutch, pooled and analyzed for residues.
2. PCB concentrations are based on Aroclor 1254/1260 1:1 mixture.

Note: Letters refer to significant differences between sites for each year.

Source: C. Bishop, and R. Turle, Canadian Wildlife Service unpublished data.

doubled in 1988 as compared to 1984 at Lynde Creek and at Hamilton as compared to 1989 levels. Notably, these pesticide levels showed a distinct peak in 1988.

PCB concentrations declined in each year of sampling from 1984 to 1989 at Algonquin Park and Rondeau Park. However, at Lynde Creek, PCB levels increased between 1984 and 1989 with lowest levels recorded in 1988. At Cranberry Marsh levels increased over 100% between 1988 and 1989. At Hamilton Harbour, PCB levels decreased significantly between 1984 and 1988 but increased significantly between 1988 and 1989.

By 1988, 2,3,7,8-TCDD concentrations declined by 50% at Hamilton Harbour relative to 1984 levels. However, 1,2,3,7,8-PnCDD had not declined at all and 1,2,3,6,7,8-HxCDF had increased from nondeductible levels to 6 pg/g between years (Table 15).

Contaminant levels have not generally declined in turtle eggs in the Great Lakes since 1984. In many cases, they have increased substantially. An interesting aspect of these temporal trends in PCBs, PCDDs and PCDFs and pesticides is that changes in PCB and dioxin levels do not coincide with variation in DDE and mirex levels.

TABLE 15. CONCENTRATIONS OF DIOXIN AND FURAN CONGENERS[1] (PPT, WET WEIGHT) IN SNAPPING TURTLE EGGS[2], 1988

			PCDDs (Dioxins)			PCDFs (Furans)		
Site	Year	N	2,3,7,8-	1,2,3,7,8-	1,2,3,6,7,8-	1,2,4,8,9/2,3,4,6,7-	2,3,4,7,8/1,3,4,8,9-	%Lipid
Hamilton Harbour/ Cootes Paradise	1984	3	67	6	4	N/A	N/A	6.0
	1988	7	33	7	6	ND	17	5.45
Lynde Creek	1988	10	40	44	33	5	26	5.76
Cranberry Marsh	1988	8	7	5	4	ND	4	5.10
Algonquin Park	1988	8	ND	ND	ND	ND	ND	5.69

1. Data reported here are for those congeners where values exceeded minimum detectable concentration (signal/noise = 3).
2. Samples at each site were pooled for a single analysis. N refers to the number of eggs per pool. Moisture levels in all eggs averaged between 70 and 75%

ND = not detected, N/A = not analyzed

Source: C. Bishop, Canadian Wildlife Service, unpublished data; analyses conducted by R.J. Norstrom, Canadian Wildlife Service.

10. DISCUSSION

Monitoring of wildlife residues has provided valuable information on the magnitude, trends and distribution of organochlorine contaminants in the Great Lakes basin. There are very few organochlorine contaminants where the concentrations in the late 1980s are not substantially lower than they were in the 1970s. However, substantial residues of xenobiotic chemicals remain in aquatic birds, mammals and reptiles. In addition, there are many unidentified compounds in wildlife tissues. In species where there are consistent year to year data, such as the herring gull, the rate at which contaminants are decreasing can be ascertained. On a lake-wide basis, the concentrations of many compounds decreased rapidly during the 1970s, especially DDE and PCBs. In the 1980s, these rates of decline are not as rapid and in many cases have levelled off.

Geographic comparisons of organochlorine levels in herring gulls show that it can be a good indicator of both lakewide and local contamination. For example, high mirex levels in Lake Ontario gull eggs can be directly related to mirex manufacturing plants at Oswego, New York and on the Niagara River which ceased operations in the 1970s. TCDD levels in Lake Ontario and Saginaw Bay, Lake Huron are attributable to historical chlorophenol manufacture on the Niagara River and in the Saginaw drainage basin.

Table 16 shows the contaminant burdens in eggs of different species. Further study is needed to distinguish between the ecological, behavioural and physiological factors which influence residue levels. Volume II of this report examines the effects of these burdens on the physiology, reproductive success and population levels of selected species.

TABLE 16. SUMMARY OF PCB AND DDE CONCENTRATIONS (PPM, WET WEIGHT) IN VARIOUS GREAT LAKES WILDLIFE SPECIES IN LAKE ONTARIO, 1981[1,2]

SPECIES	PCB[3] Aroclor	DDE	LOCATION
HERRING GULL	86	12	SNAKE ISLAND
CASPIAN TERN	39	5.2	PIGEON ISLAND
DOUBLE-CRESTED CORMORANT	38	5.8	LITTLE GALLOO ISLAND
BLACK-CROWNED NIGHT-HERON	24	4.8	PIGEON ISLAND
MINK	21	2.6	WHITBY-COBOURG SHORELINE
COMMON TERN	10.4	2.5	LESLIE ST. SPIT
BALD EAGLE	8.6	5.4	LAKE ERIE SOUTH SHORELINE[4]
SNAPPING TURTLE	8.6	0.23	HAMILTON HARBOUR

1. Data were available for 1981 for all species except the snapping turtle (1984).
2. All concentrations are from egg samples (wet weight) except mink which is a liver sample (lipid weight).
3. In order to facilitate comparisons among species PCB Aroclor (1254/1260 1:1 mixture) value is used for all species.
4. No nests were observed along the Lake Ontario shoreline.

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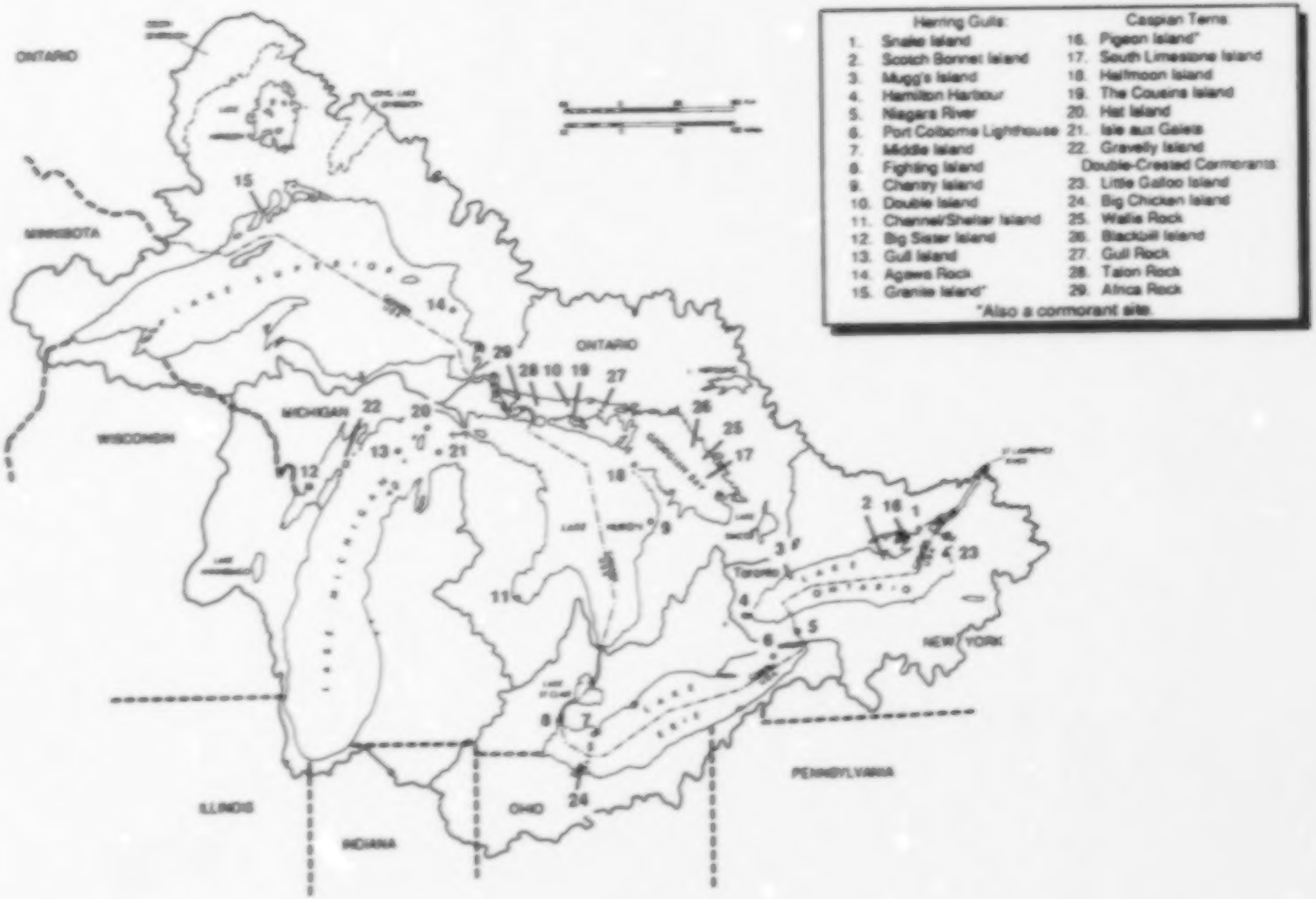
Herring Gulls:
1. Snake Island
2. Scotch Bonnet Island
3. Mugg's Island
4. Hamilton Harbour
5. Niagara River
6. Port Colborne Lighthouse
7. Middle Island
8. Fighting Island
9. Chantry Island
10. Double Island
11. Channel/Shelter Island
12. Big Sister Island
13. Gull Island
14. Agawa Rock
15. Granite Island*
Caspian Terns
16. Pigeon Island*
17. South Limestone Island
18. Halfmoon Island
19. The Cousins Island
20. Hat Island
21. Isle aux Galets
22. Gravelly Island
Double-Crested Cormorants:
23. Little Galloo Island
24. Big Chicken Island
25. Wallis Rock
26. Blackbill Island
27. Gull Rock
28. Talon Rock
29. Africa Rock
*Also a cormorant site.
ONTARIO
MINNESOTA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
PENNSYLVANIA
NEW YORK
Toronto
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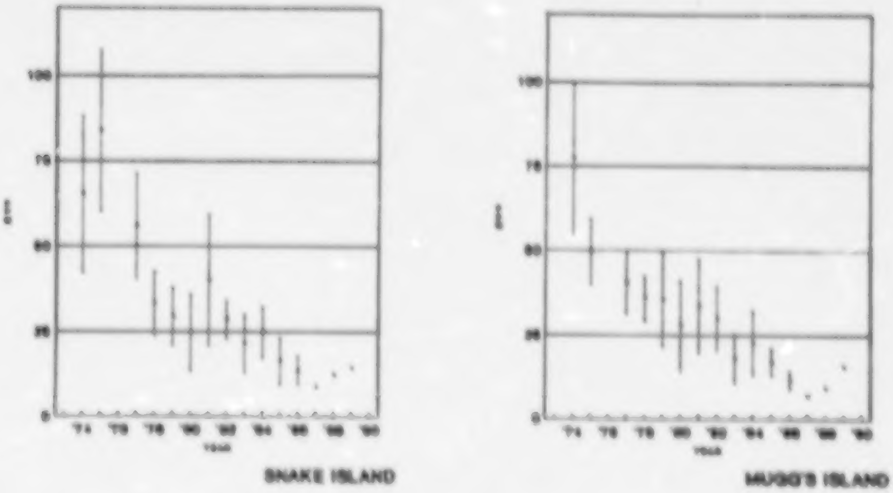
Figure 1

Herring gull, caspian tern and double-crested cormorant colonies studied in the Great Lakes basin.

LAKE ONTARIO

Σ PCB CONCENTRATIONS



DDE CONCENTRATIONS

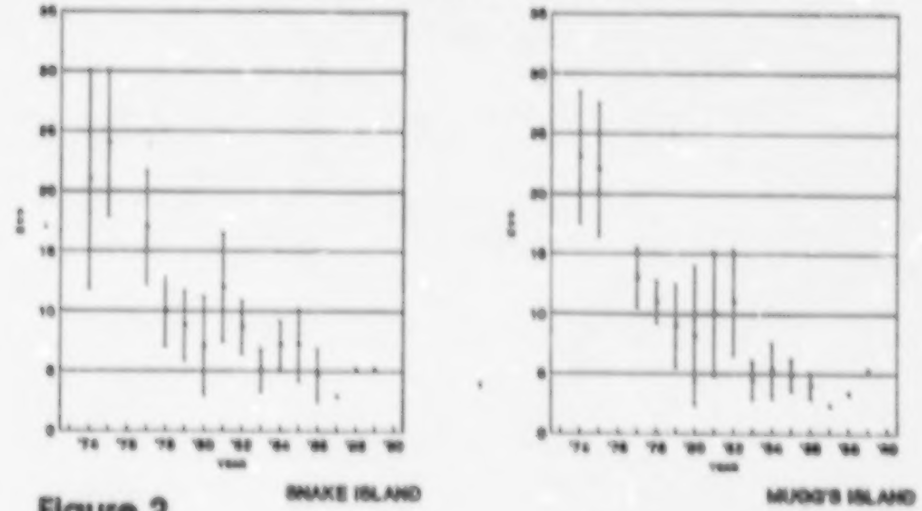


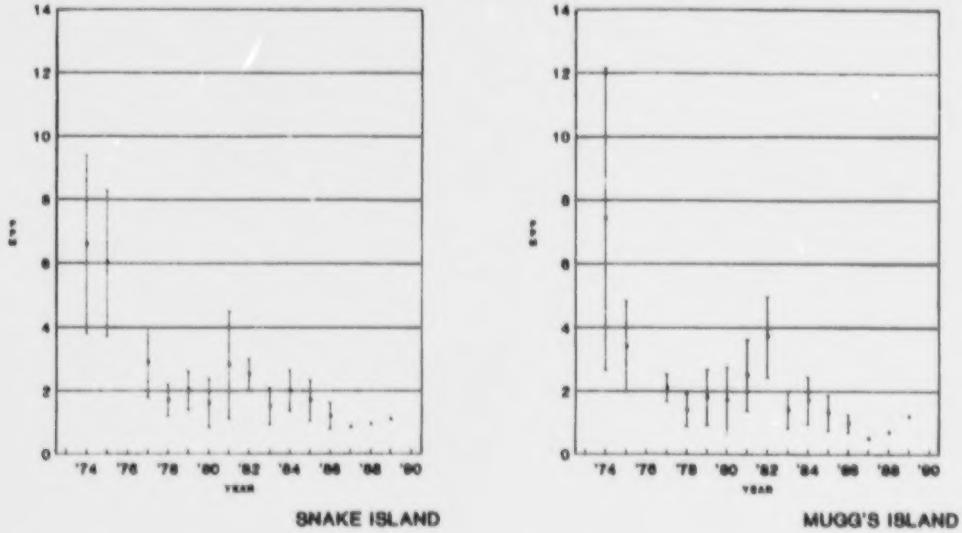
Figure 2

Mean concentrations of ΣPCB (see text) and DDE in herring gull eggs from Lake Ontario Snake and Mugg's Island colonies (ppm, wet weight). Means with standard deviation are based on samples of 9-11 eggs; means without S.D. are based on one sample of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

LAKE ONTARIO

MIREX CONCENTRATIONS



HCB CONCENTRATIONS

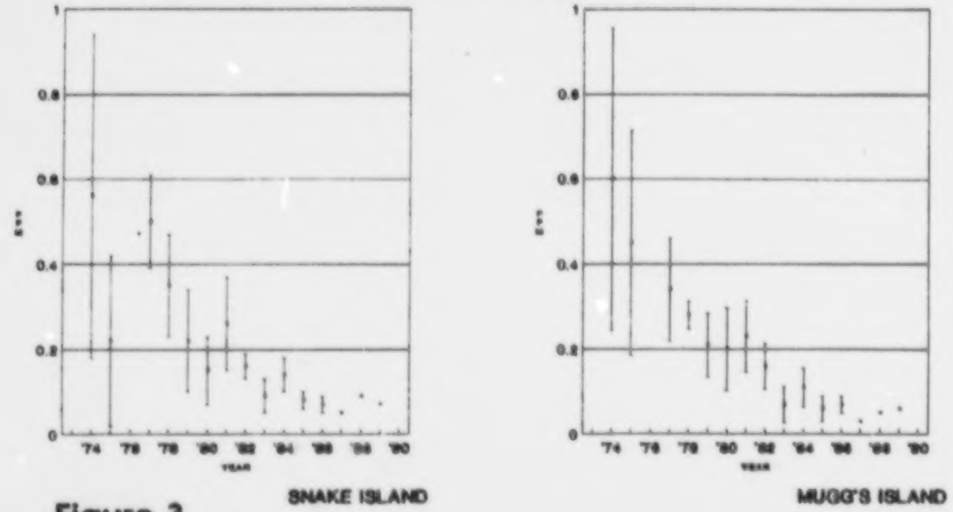


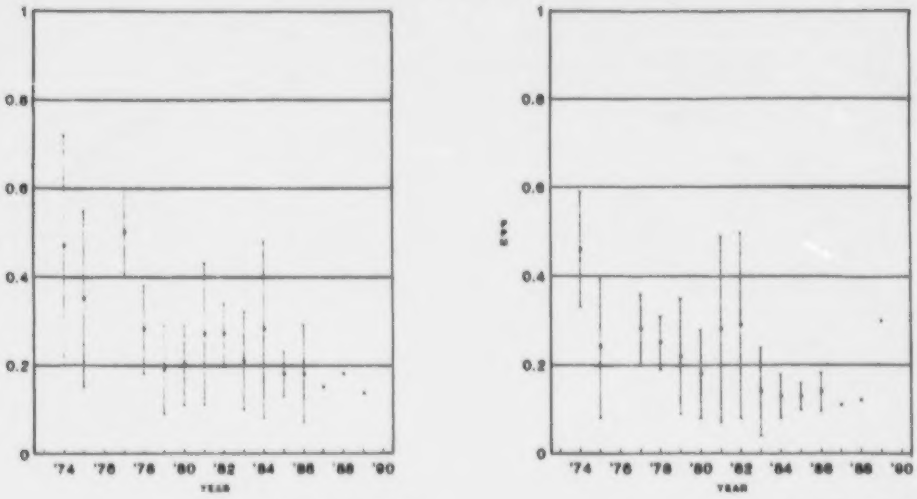
Figure 3

Mean concentrations of mirex and HCB in herring gull eggs from Lake Ontario: Snake and Mugg's Island colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

LAKE ONTARIO

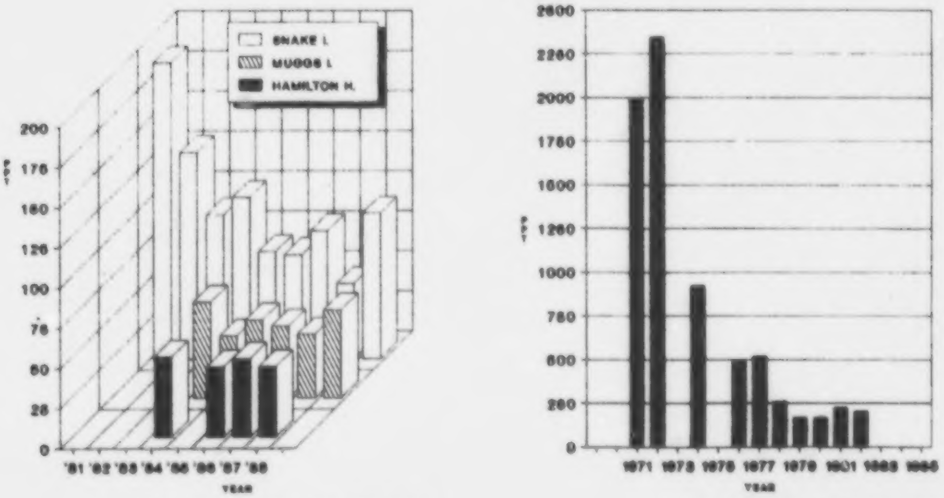
DIELDRIN CONCENTRATIONS



SNAKE ISLAND

MUGG'S ISLAND

TCDD CONCENTRATIONS



HAMILTON H., MUGG'S I., SNAKE I.

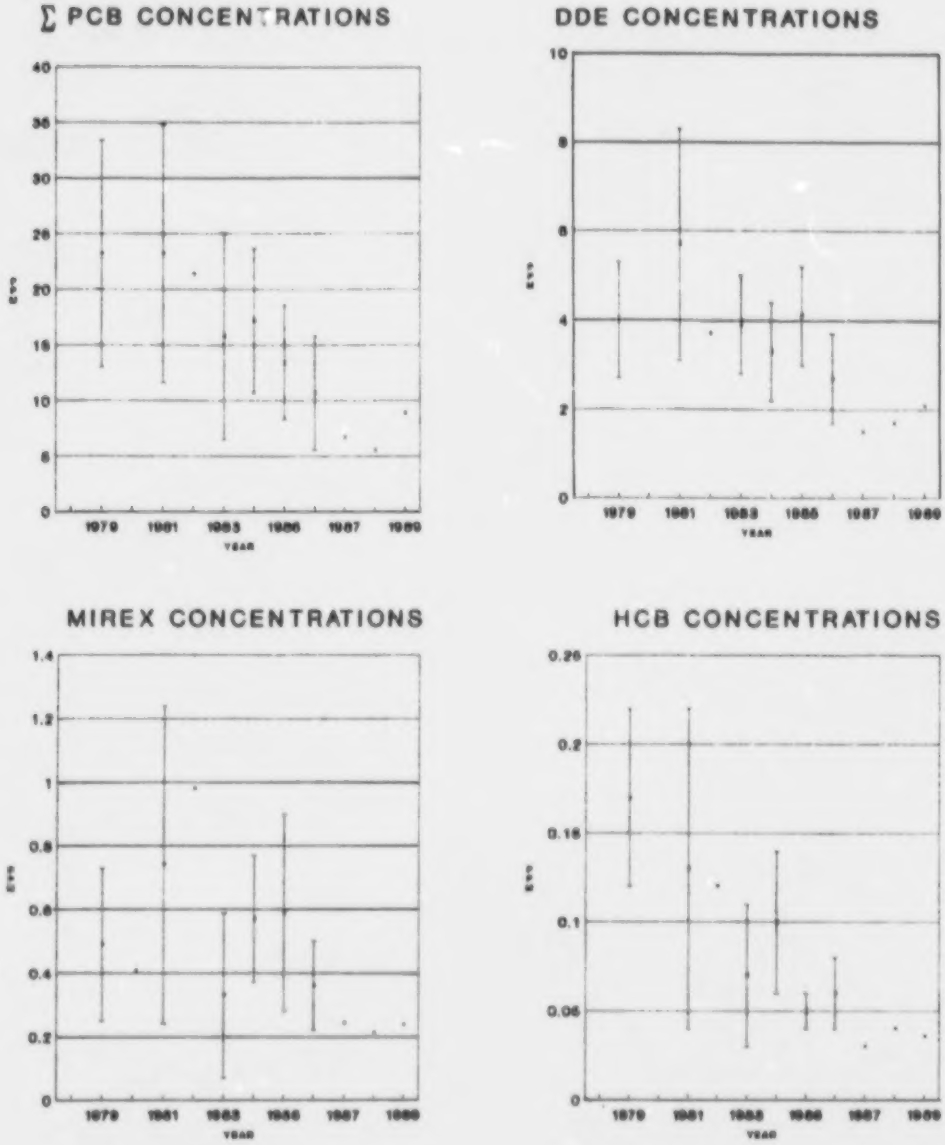
SCOTCH BONNET ISLAND

Figure 4

Mean concentrations of dieldrin and TCDD in herring gull eggs from Lake Ontario colonies (ppm, wet weight for dieldrin and ppt for TCDD). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service) for dieldrin data and R. J. Norstrom (CWS) for TCDD data.

NIAGARA RIVER



∑ PCB CONCENTRATIONS

DDE CONCENTRATIONS

MIREX CONCENTRATIONS

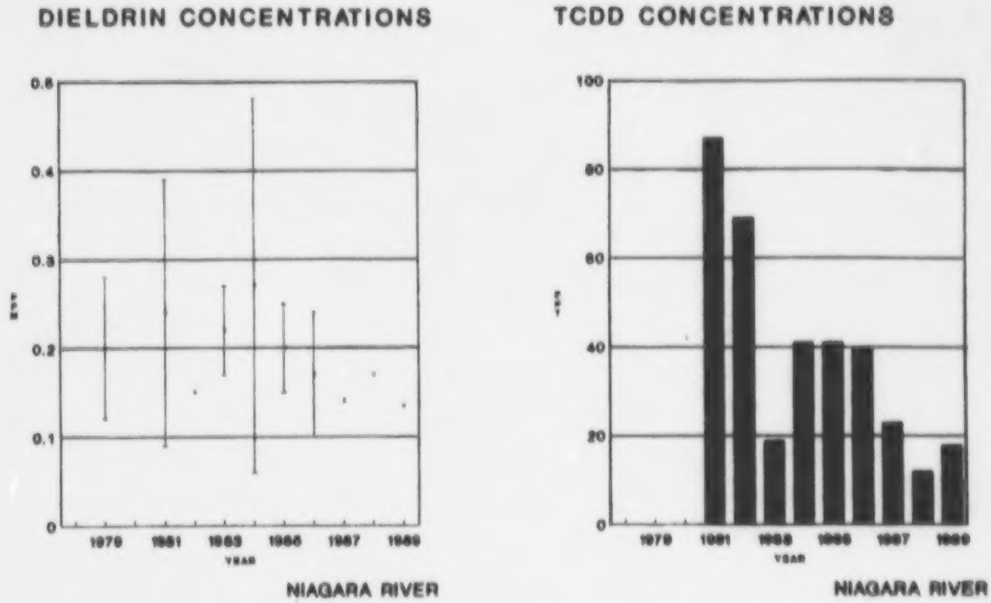
HCB CONCENTRATIONS

Figure 5

Mean concentrations organochlorine contaminants in herring gull eggs from the Niagara River colony (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service)

NIAGARA RIVER



DIELDRIN CONCENTRATIONS

TCDD CONCENTRATIONS

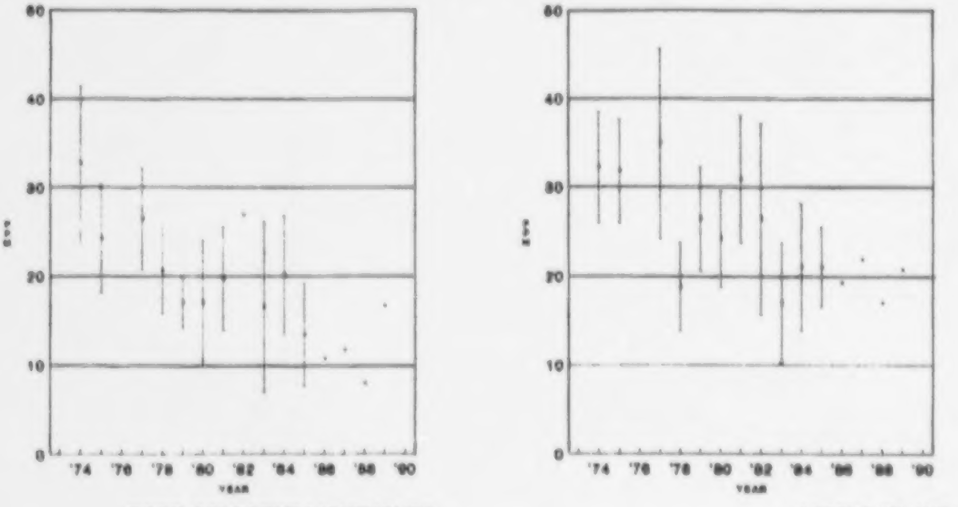
Figure 6

Mean concentrations of dieldrin and TCDD in herring gull eggs from the Niagara River colony (ppm, wet weight for dieldrin and ppt for TCDD). Means without standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service) for dieldrin data and R. J. Norstrom (CWS) for TCDD data.

LAKE ERIE

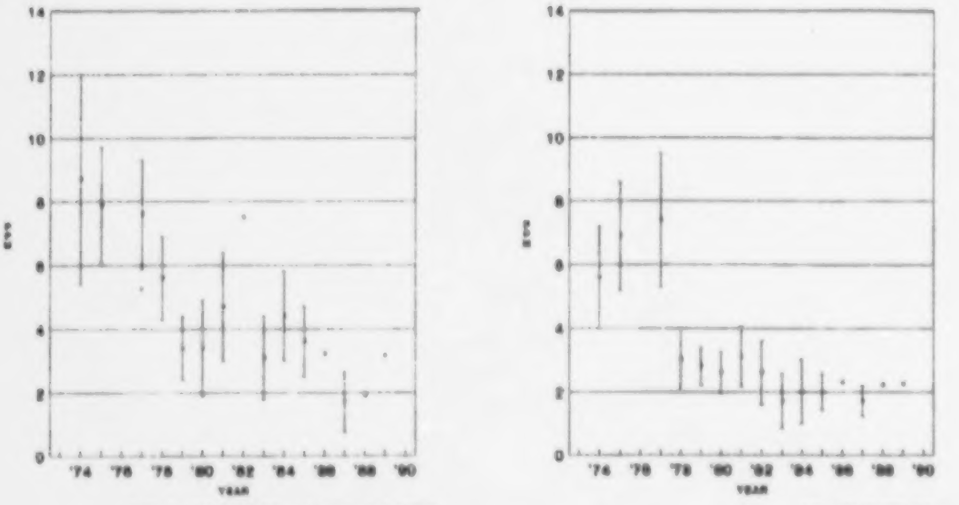
Σ PCB CONCENTRATIONS



PORT COLBORNE LIGHTHOUSE

MIDDLE ISLAND

DDE CONCENTRATIONS



PORT COLBORNE LIGHTHOUSE

MIDDLE ISLAND

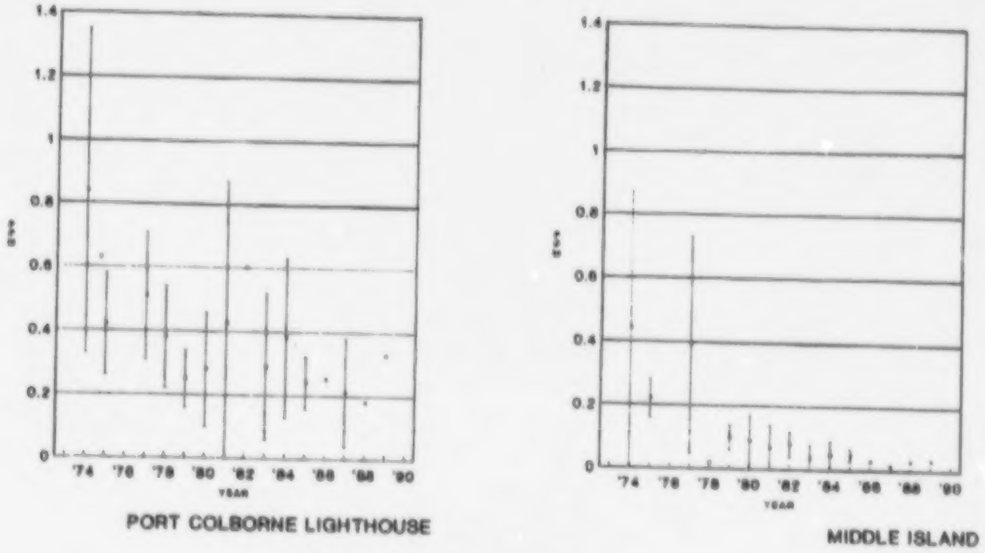
Figure 7

Mean concentrations of ΣPCB and DDE in herring gull eggs from Lake Erie Middle Island and Port Colborne Lighthouse colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs, means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service)

LAKE ERIE

MIREX CONCENTRATIONS



HCB CONCENTRATIONS

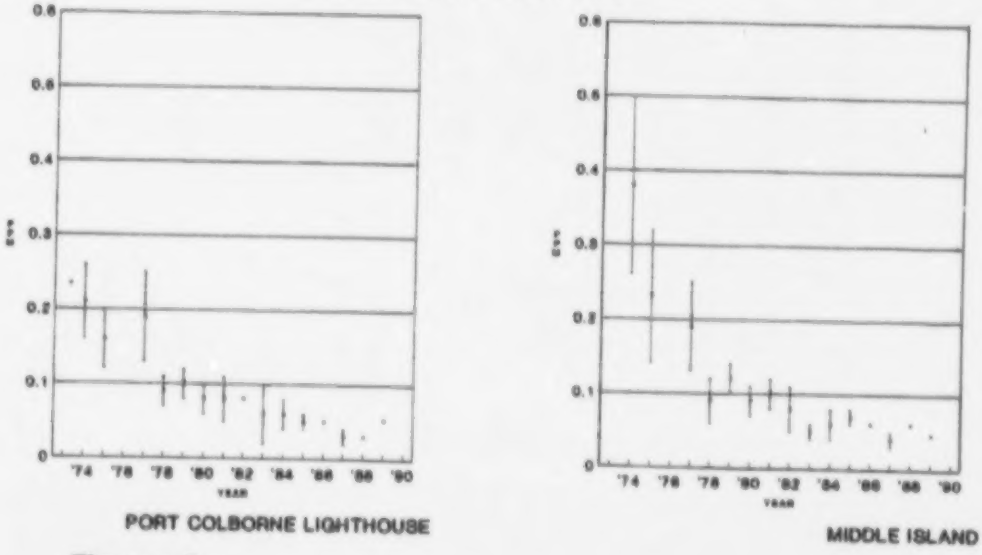
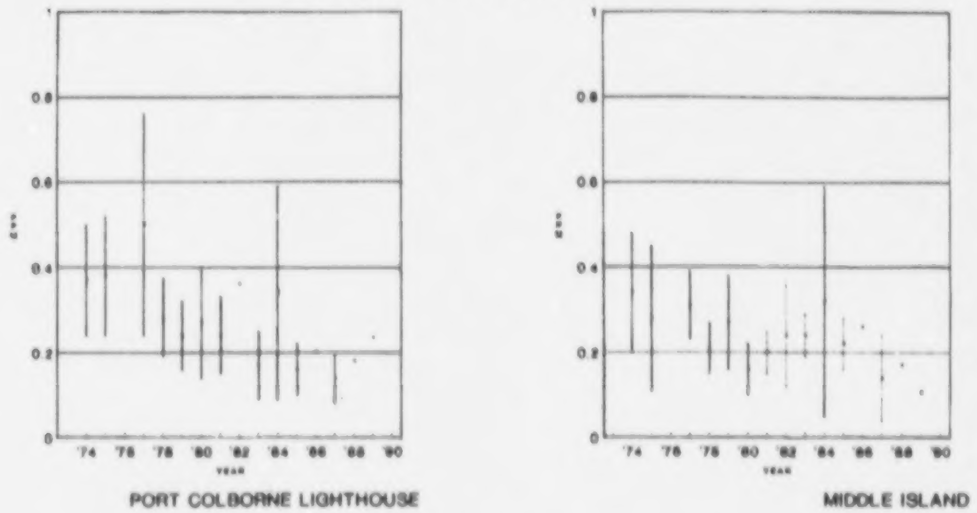


Figure 8

Mean concentrations of mirex and HCB in herring gull eggs from Lake Erie Middle Island and Port Colborne Lighthouse colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

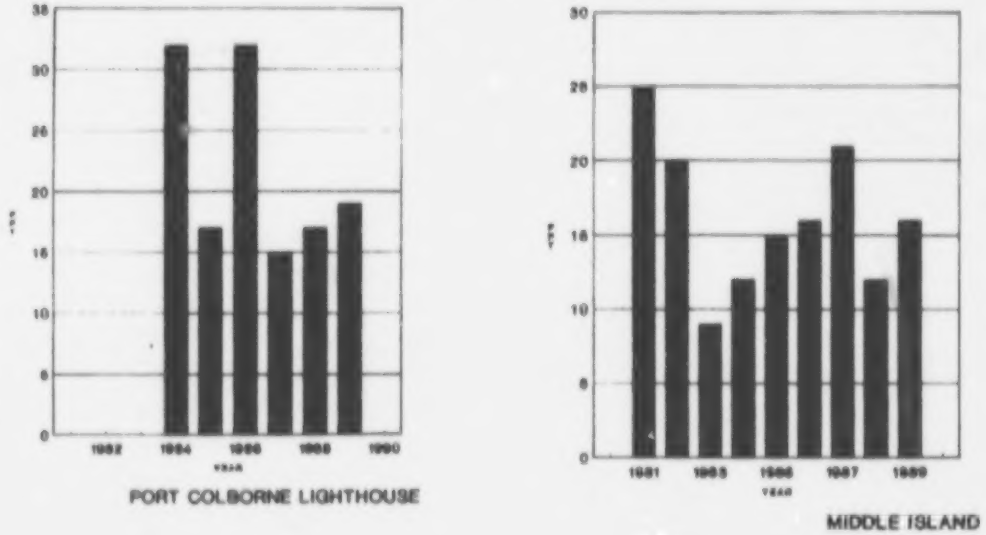
LAKE ERIE



DIELDRIN CONCENTRATIONS

PORT COLBORNE LIGHTHOUSE

MIDDLE ISLAND



TCDD CONCENTRATIONS

PORT COLBORNE LIGHTHOUSE

MIDDLE ISLAND

Figure 9

Mean concentrations of dieldrin and TCDD in herring gull eggs from Lake Erie Middle Island and Port Colborne Lighthouse colonies (ppm, wet weight for dieldrin; ppt, wet weight for TCDD). Means without standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service) for dieldrin data and R. J. Norstrom for TCDD data.

DETROIT RIVER

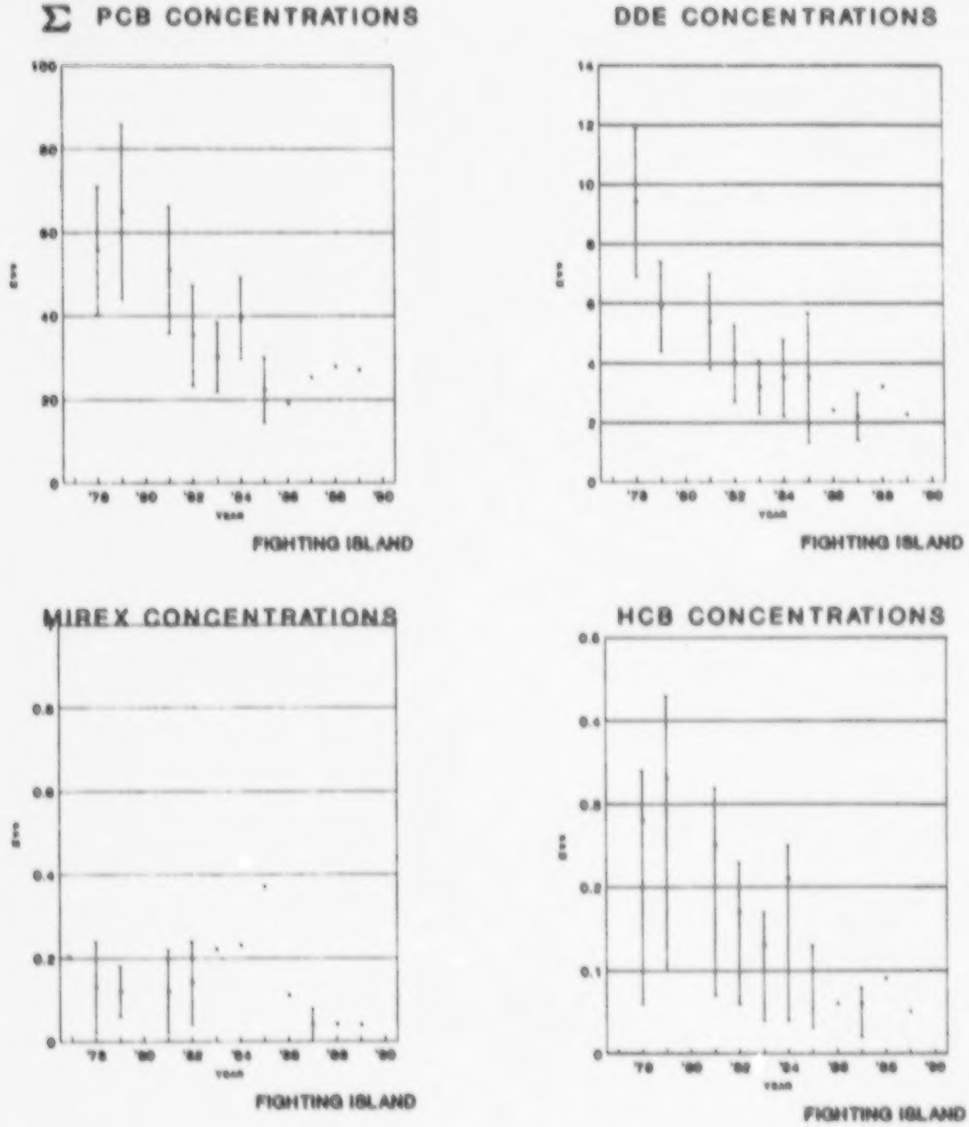
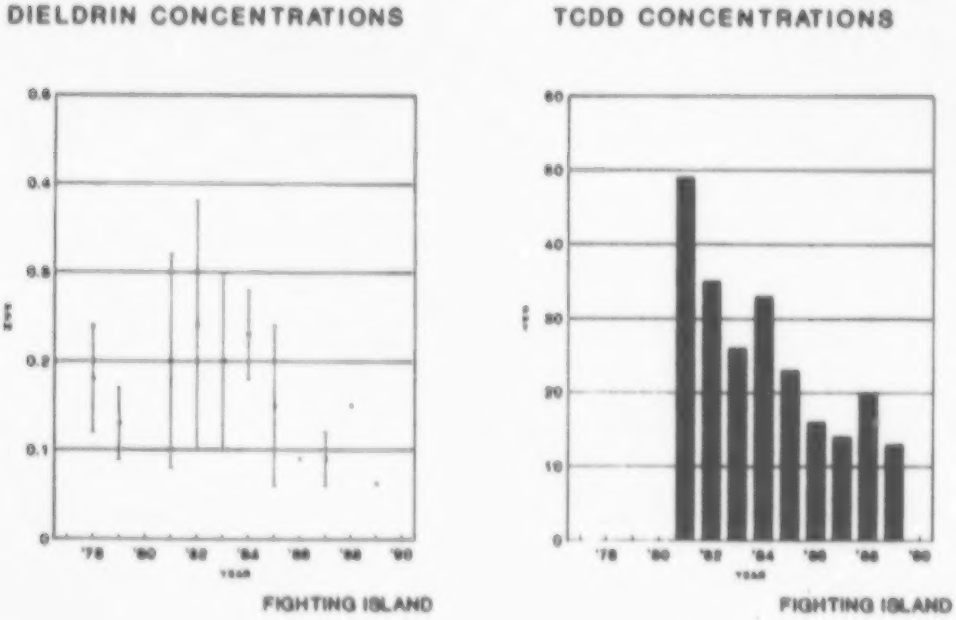


Figure 10

Mean concentrations of contaminants in herring gull eggs from the Detroit River, Fighting Island colony (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

DETROIT RIVER



DIELDRIN CONCENTRATIONS

TCDD CONCENTRATIONS

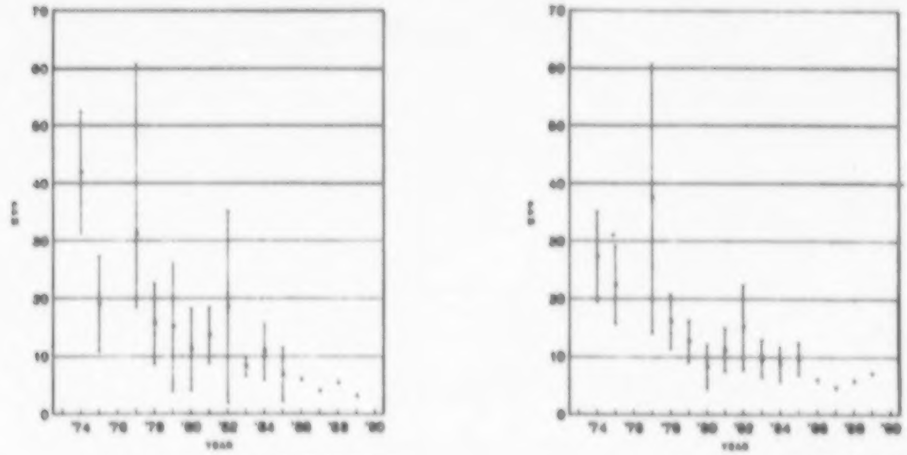
Figure 11

Mean concentrations of dieldrin and TCDD in herring gull eggs from the Detroit River, Fighting Island colony (ppm, wet weight for dieldrin; ppt for TCDD). Means with standard deviations are based on a sample of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service) for dieldrin data and R. J. Norstrom (CWS) for TCDD data.

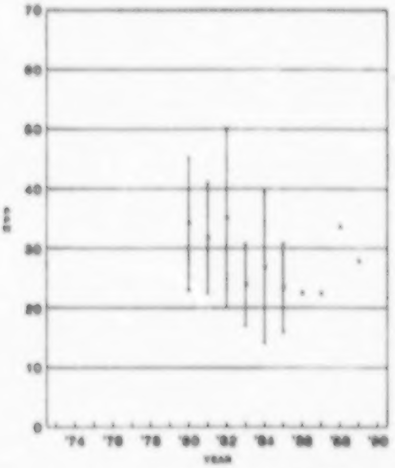
LAKE HURON

∑ PCB CONCENTRATIONS



CHANTRY ISLAND

DOUBLE ISLAND



CHANNEL/SHELTER ISLAND

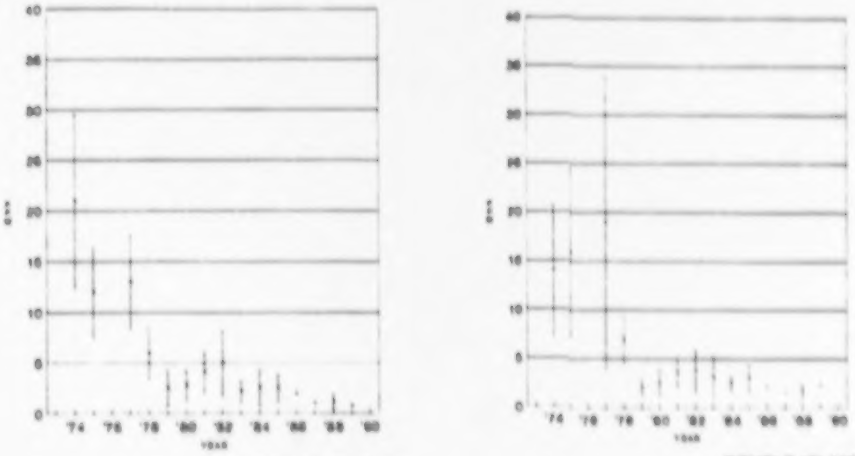
Figure 12

Mean concentrations of ΣPCB in herring gull eggs from Lake Huron Double, Chantry and Channel/Shelter Island colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

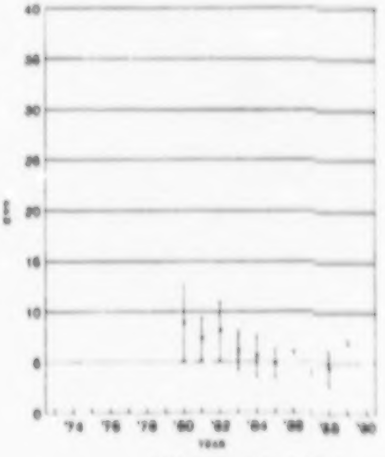
LAKE HURON

DDE CONCENTRATIONS



CHANTRY ISLAND

DOUBLE ISLAND



CHANNEL/SHELTER ISLAND

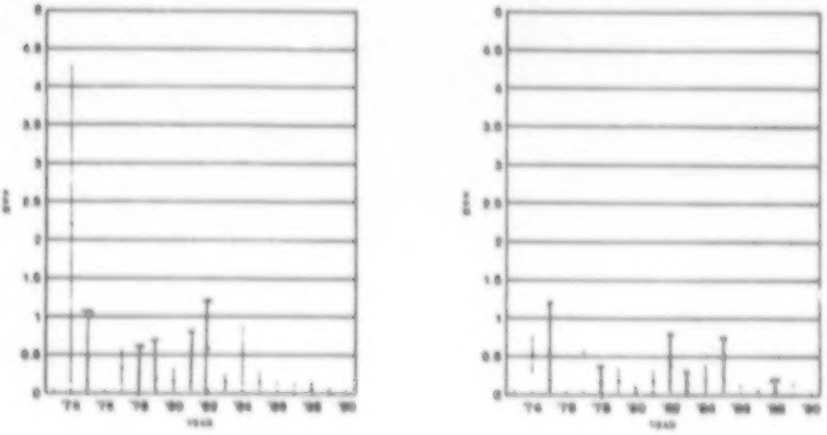
Figure 13

Mean concentrations of DDE in herring gull eggs from Lake Huron Double, Chantry and Channel/Shelter Island colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

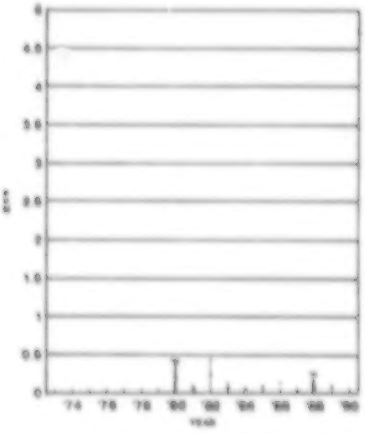
LAKE HURON

MIREX CONCENTRATIONS



CHANTRY ISLAND

DOUBLE ISLAND



CHANNEL/SHELTER ISLAND

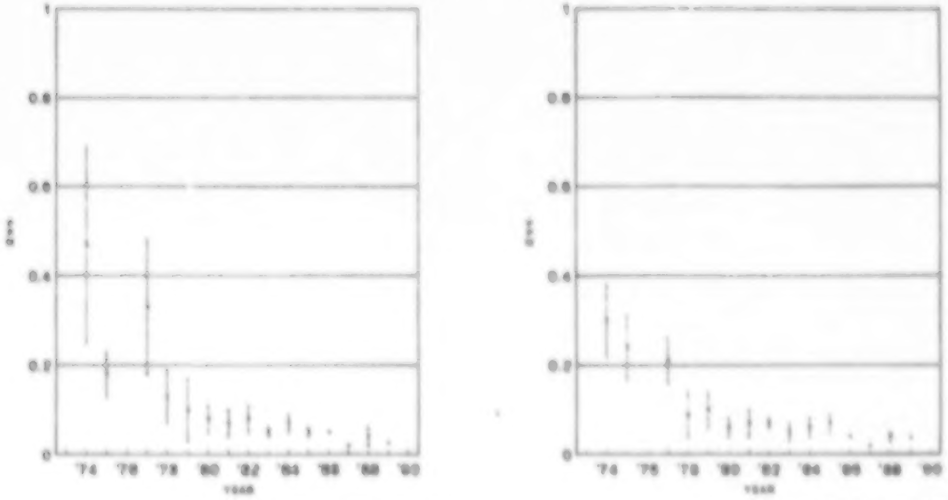
Figure 14

Mean concentrations of mirex in herring gull eggs from Lake Huron Double, Chantry and Channel/Shelter Island colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

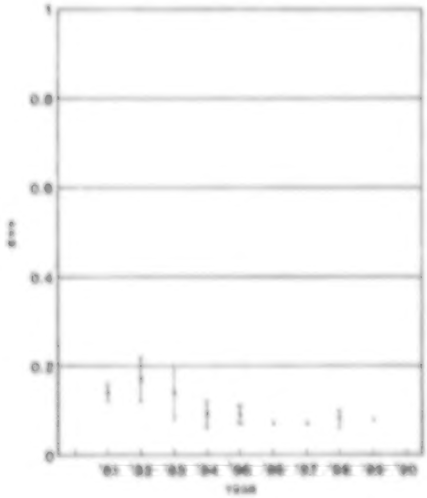
LAKE HURON

HCB CONCENTRATIONS



CHANTRY ISLAND

DOUBLE ISLAND



CHANNEL/SHELTER ISLAND

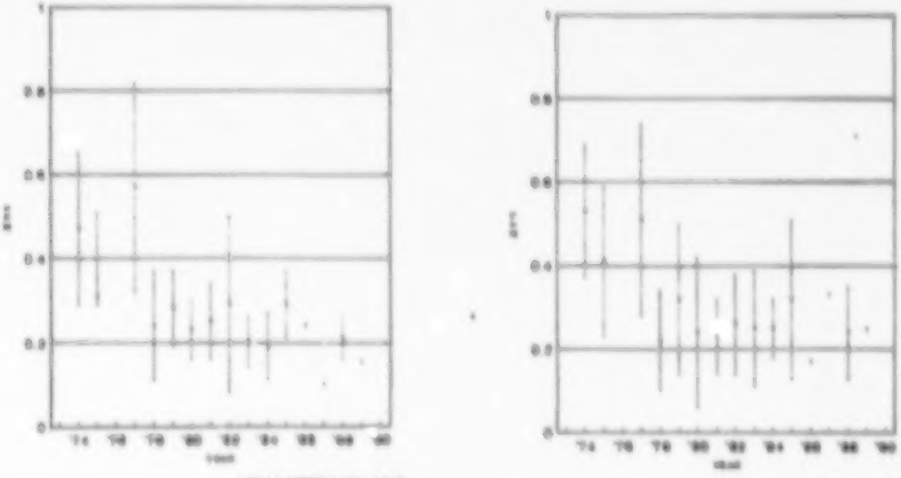
Figure 15

Mean concentrations of HCB in herring gull eggs from Lake Huron Double, Chantry and Channel/ Shelter Island colonies (ppm, wet weight). Means withou standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

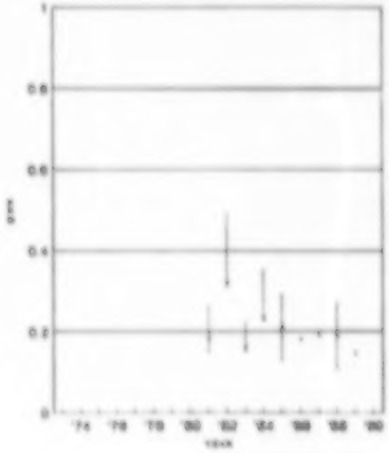
LAKE HURON

DIELDRIN CONCENTRATIONS



CHANTRY ISLAND

DOUBLE ISLAND



CHANNEL/SHELTER ISLAND

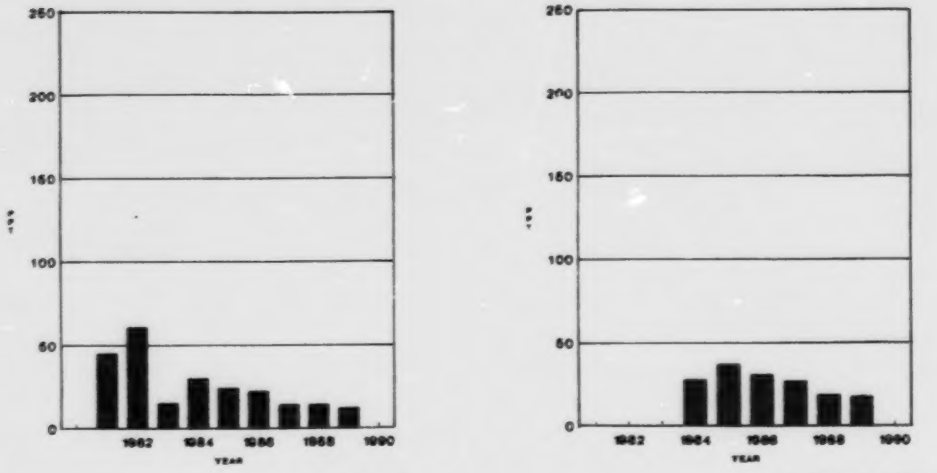
Figure 16

Mean concentrations of dieldrin in herring gull eggs from Lake Huron Double, Chantry and Channel/Shelter Island colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

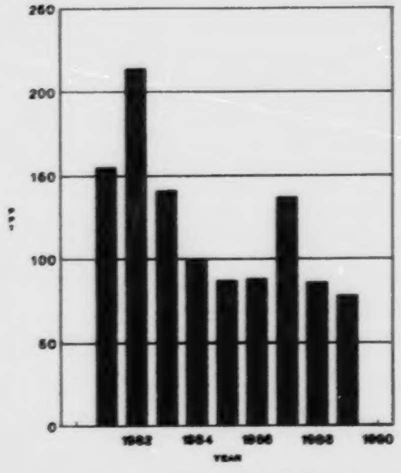
LAKE HURON

TCDD CONCENTRATIONS



CHANTRY ISLAND

DOUBLE ISLAND



CHANNEL/SHELTER ISLAND

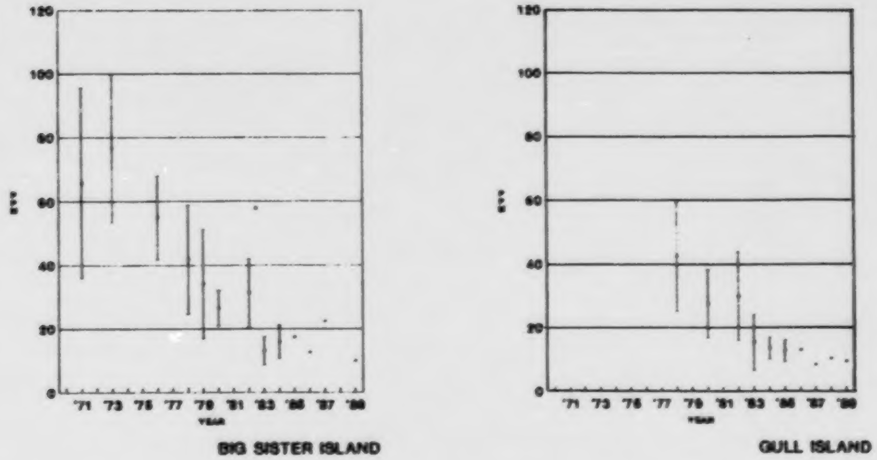
Figure 17

Mean concentrations of TCDD in herring gull eggs from Lake Huron Double, Chantry and Channel/Shelter Island colonies (ppt, wet weight). Results are based on one analysis of a 10 egg pool.

Source: R. J. Norstrom (Canadian Wildlife Service).

LAKE MICHIGAN

∑ PCB CONCENTRATIONS



DDE CONCENTRATIONS

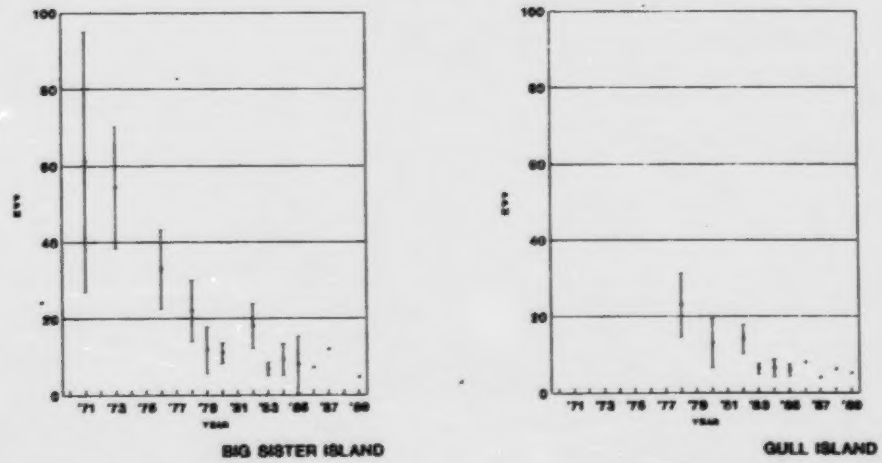


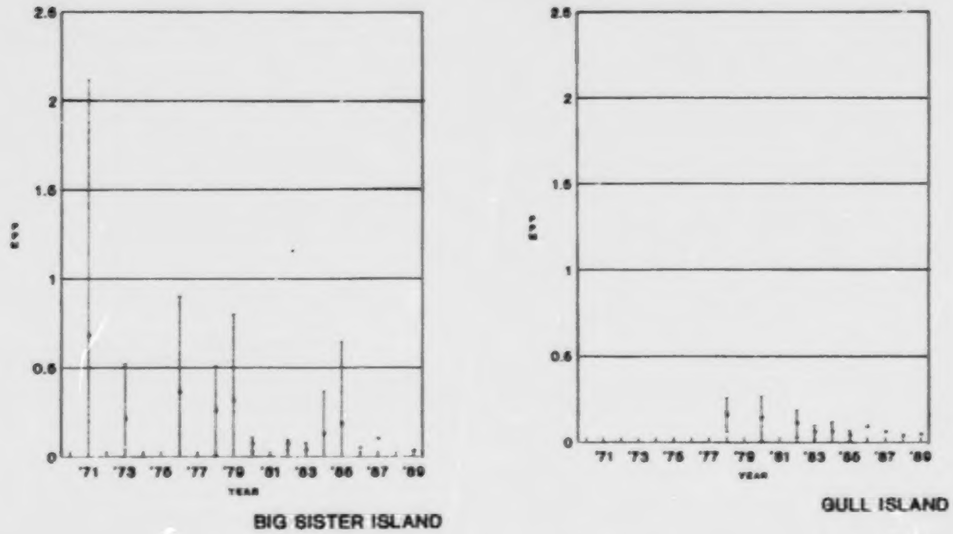
Figure 18

Mean concentrations of ΣPCB and DDE in herring gull eggs from Lake Michigan Big Sister and Gull Island colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

LAKE MICHIGAN

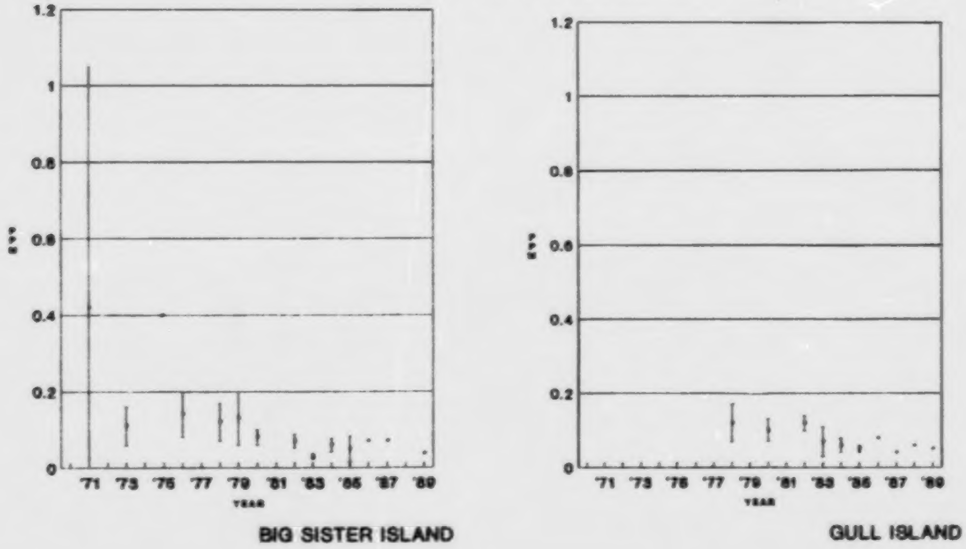
MIREX CONCENTRATIONS



BIG SISTER ISLAND

GULL ISLAND

HCB CONCENTRATIONS



BIG SISTER ISLAND

GULL ISLAND

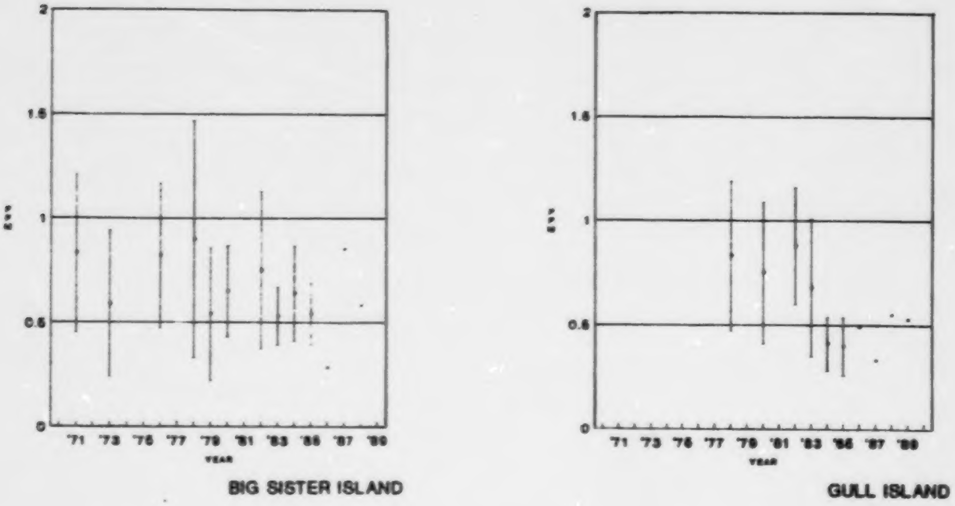
Figure 19

Mean concentrations of mirex and HCB in herring gull eggs from Lake Michigan Big Sister and Gull Island colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

LAKE MICHIGAN

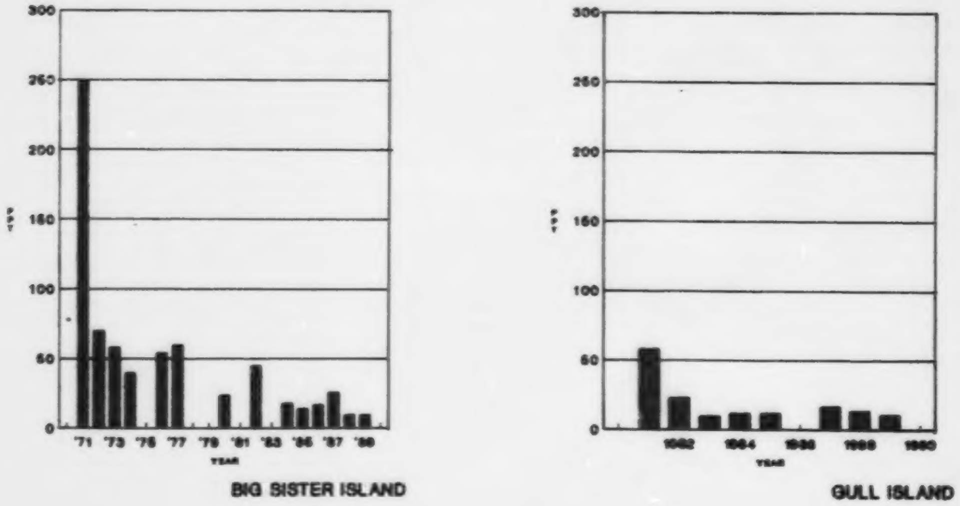
DIELDRIN CONCENTRATIONS



BIG SISTER ISLAND

GULL ISLAND

TCDD CONCENTRATIONS



BIG SISTER ISLAND

GULL ISLAND

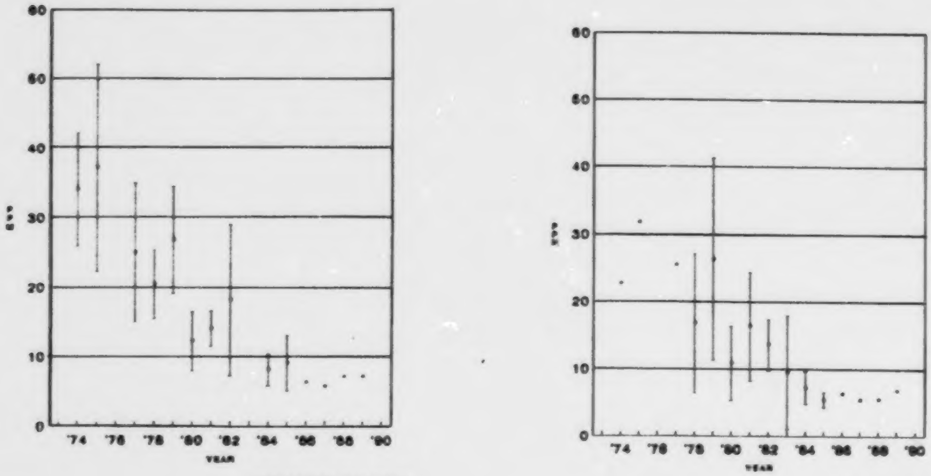
Figure 20

Mean concentrations of dieldrin and TCDD in herring gull eggs from Lake Michigan Big Sister and Gull Island colonies (ppm, wet weight for dieldrin; ppt for TCDD). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service) for dieldrin data and R. J. Norstrom (CWS) for TCDD data.

LAKE SUPERIOR

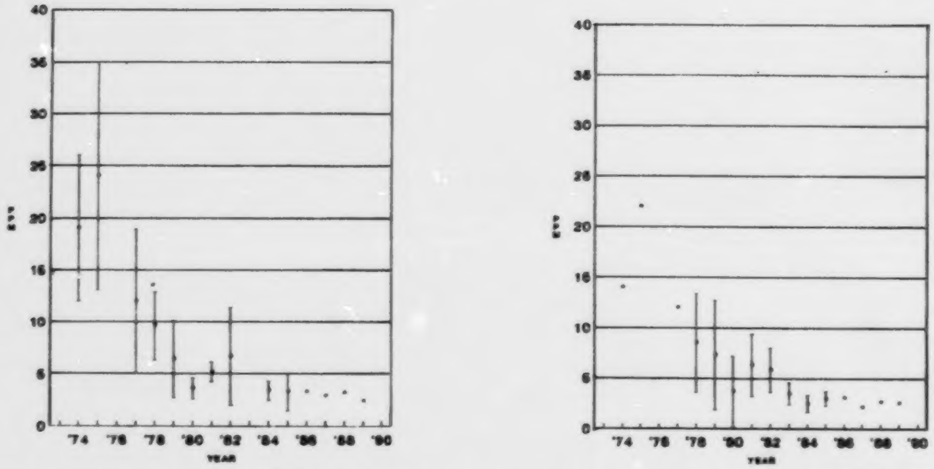
ΣPCB CONCENTRATIONS



GRANITE ISLAND

AGAWA ROCK

DDE CONCENTRATIONS



GRANITE ISLAND

AGAWA ROCK

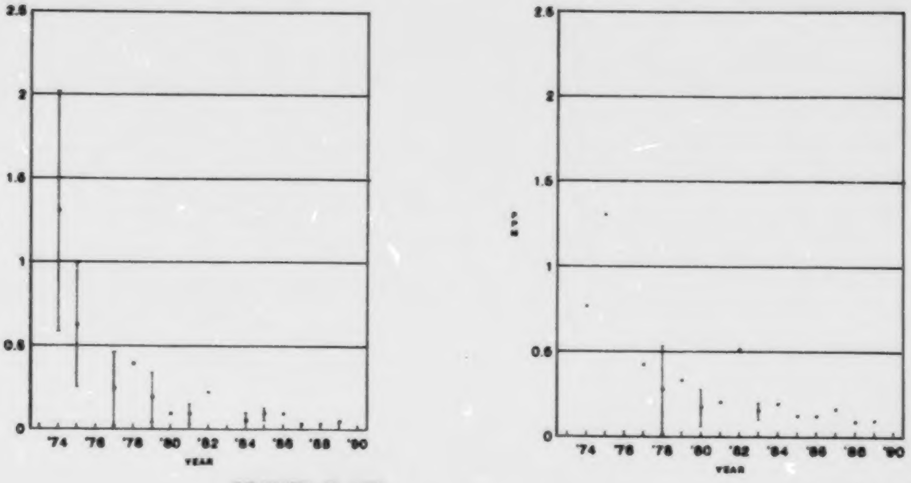
Figure 21

Mean concentratiosn of ΣPCB and DDE in herring gull eggs from Lake Superior Granite Island and Agawa Rock colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

LAKE SUPERIOR

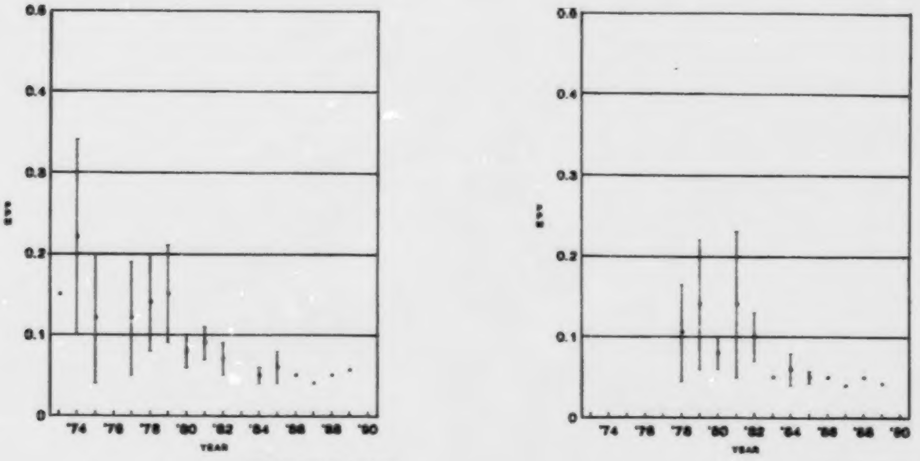
MIREX CONCENTRATIONS



GRANITE ISLAND

AGAWA ROCK

HCB CONCENTRATIONS



GRANITE ISLAND

AGAWA ROCK

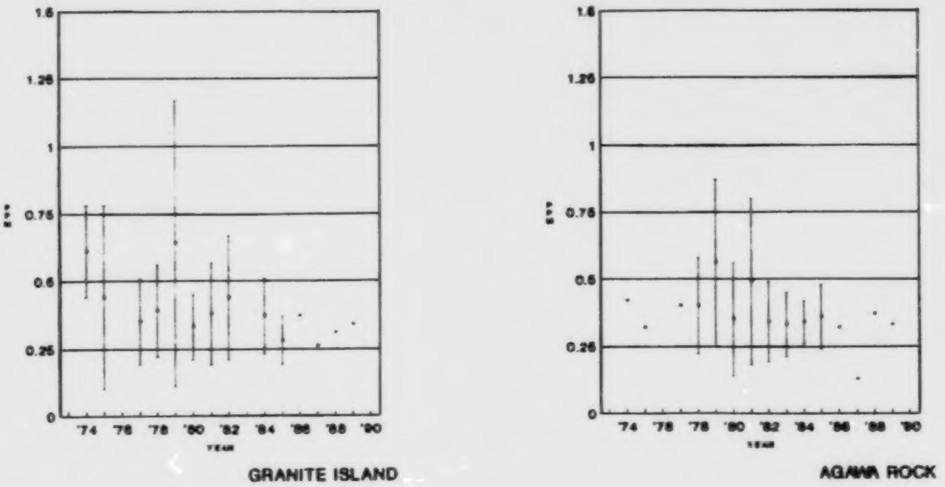
Figure 22

Mean concentrations of mirex and HCB in herring gull eggs from Lake Superior Granite Island and Agawa Rock colonies (ppm, wet weight). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service).

LAKE SUPERIOR

DIELDRIN CONCENTRATIONS



TCDD CONCENTRATIONS

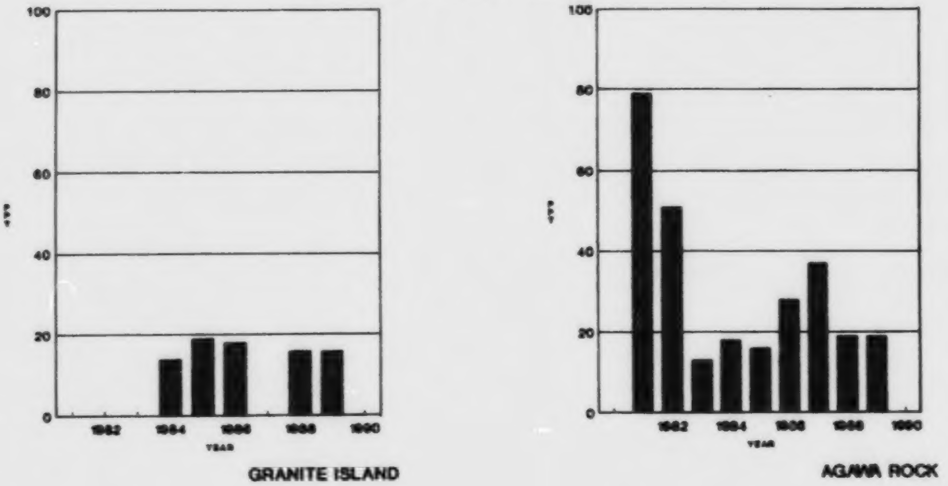
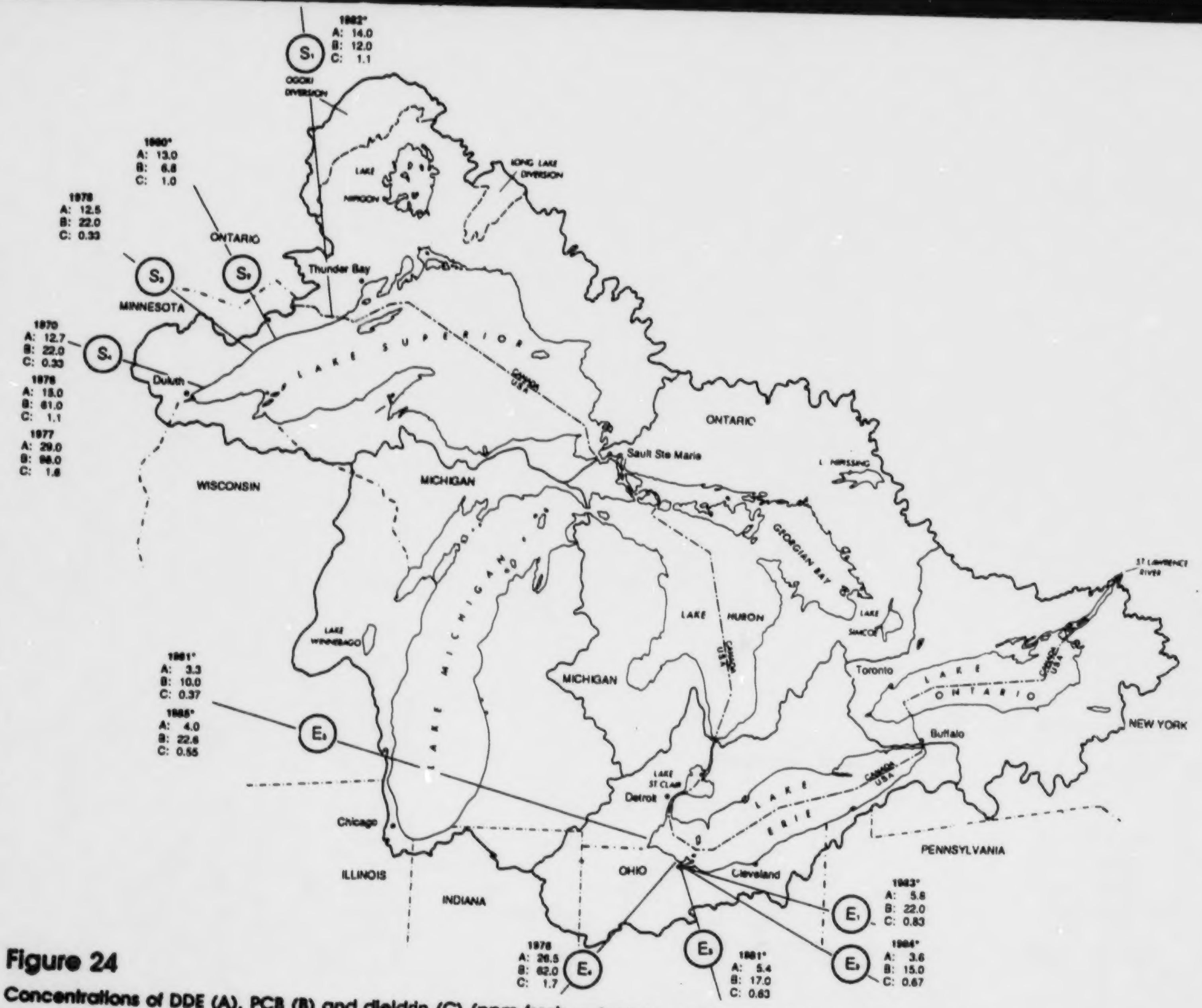


Figure 23

Mean concentrations of dieldrin and TCDD in herring gull eggs from Lake Superior Granite Island and Agawa Rock colonies (ppm, wet weight for dieldrin; ppt for TCDD). Means with standard deviations are based on samples of 9-11 eggs; means without S.D. are based on one analysis of a 10 egg pool.

Source: D.V. Weseloh (Canadian Wildlife Service) for dieldrin data. R.J. Norstrom for TCDD data.



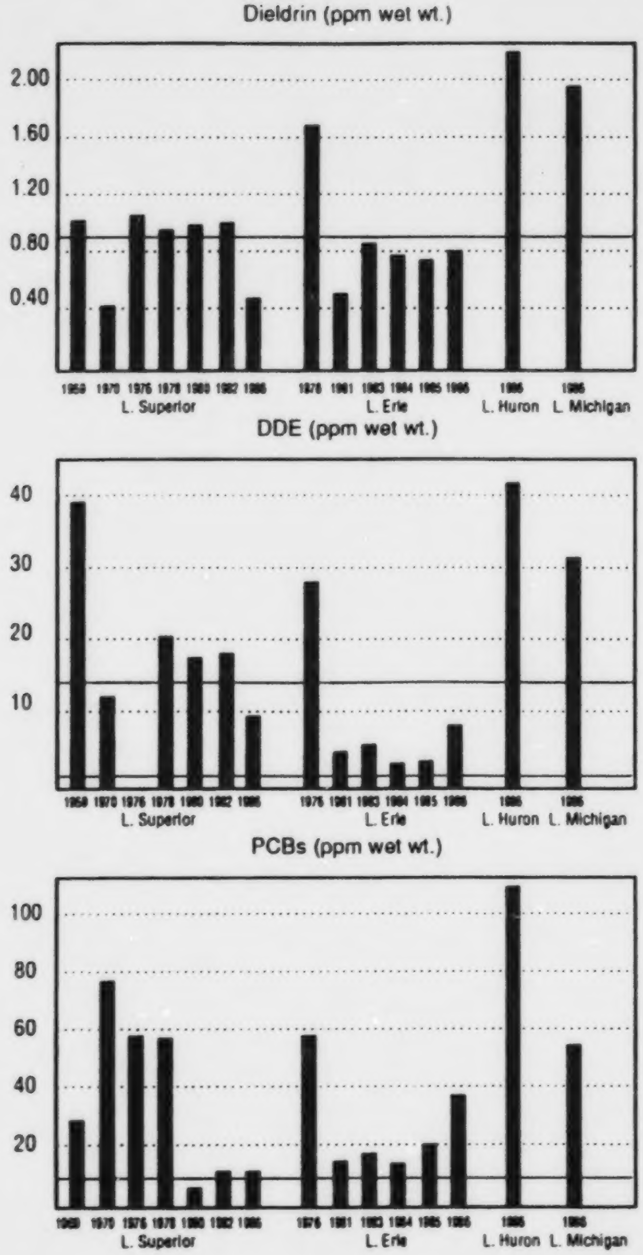
S_1
1982*
A: 14.0
B: 12.0
C: 1.1
OGOKI DIVERSION
LAKE NIPIGON
LONG LAKE DIVERSION
1980*
A: 13.0
B: 6.8
C: 1.0
ONTARIO
S_2
1978
A: 12.5
B: 22.0
C: 0.33
S_3
MINNESOTA
Thunder Bay
1970
A: 12.7
B: 22.0
C: 0.33
1976
A: 15.0
B: 61.0
C: 1.1
1977
A: 29.0
B: 98.0
C: 1.8
S_4
Duluth
LAKE SUPERIOR
CANADA USA
WISCONSIN
MICHIGAN
ONTARIO
Sault Ste Marie
L. NIPISSING
GEORGIAN BAY
LAKE SIMCOE
LAKE HURON
CANADA USA
LAKE WINNEBAGO
LAKE MICHIGAN
MICHIGAN
Toronto
LAKE ONTARIO
CANADA USA
ST LAWRENCE RIVER
NEW YORK
Buffalo
1981*
A: 3.3
B: 10.0
C: 0.37
1985*
A: 4.0
B: 22.6
C: 0.55
E_5
LAKE ST CLAIR
Detroit
LAKE ERIE
CANADA USA
Chicago
ILLINOIS
INDIANA
OHIO
Cleveland
PENNSYLVANIA
1983*
A: 5.8
B: 22.0
C: 0.83
E_1
1984*
A: 3.6
B: 15.0
C: 0.67
E_2
1981*
A: 5.4
B: 17.0
C: 0.63
E_3
1978
A: 26.5
B: 62.0
C: 1.7
E_4

Figure 24

Concentrations of DDE (A), PCB (B) and dieldrin (C) (ppm fresh weight) in eggs from bald eagle nests on the shoreline of Lakes Superior and Erie.

Source: International Joint Commission, 1987.

* Indicates the presence of sizeable colonial bird nesting areas (at least 25 nests) within 10km of eagle breeding area.



0.86 ppm associated with a 31% production rate in Scottish golden eagles (Lockie et al., 1969)

≥ 15 ppm associated with 100% reproductive failure (Wiemeyer et al., 1984)

3 ppm is critical concentration for maintaining a stable population (Wiemeyer et al., 1984)

≥ 10 ppm has "a marked effect on embryo mortality in some bird species" (Peakall, 1987)

Figure 25

Concentrations of dieldrin, DDE and PCBs in bald eagle eggs collected along the Great Lakes shores from 1969 to 1986. All concentrations are corrected for moisture loss. All n = 1 except where noted. Critical concentrations for each chemical are shown in respect to those found in the eggs.

Source: T. Colborn, in press.

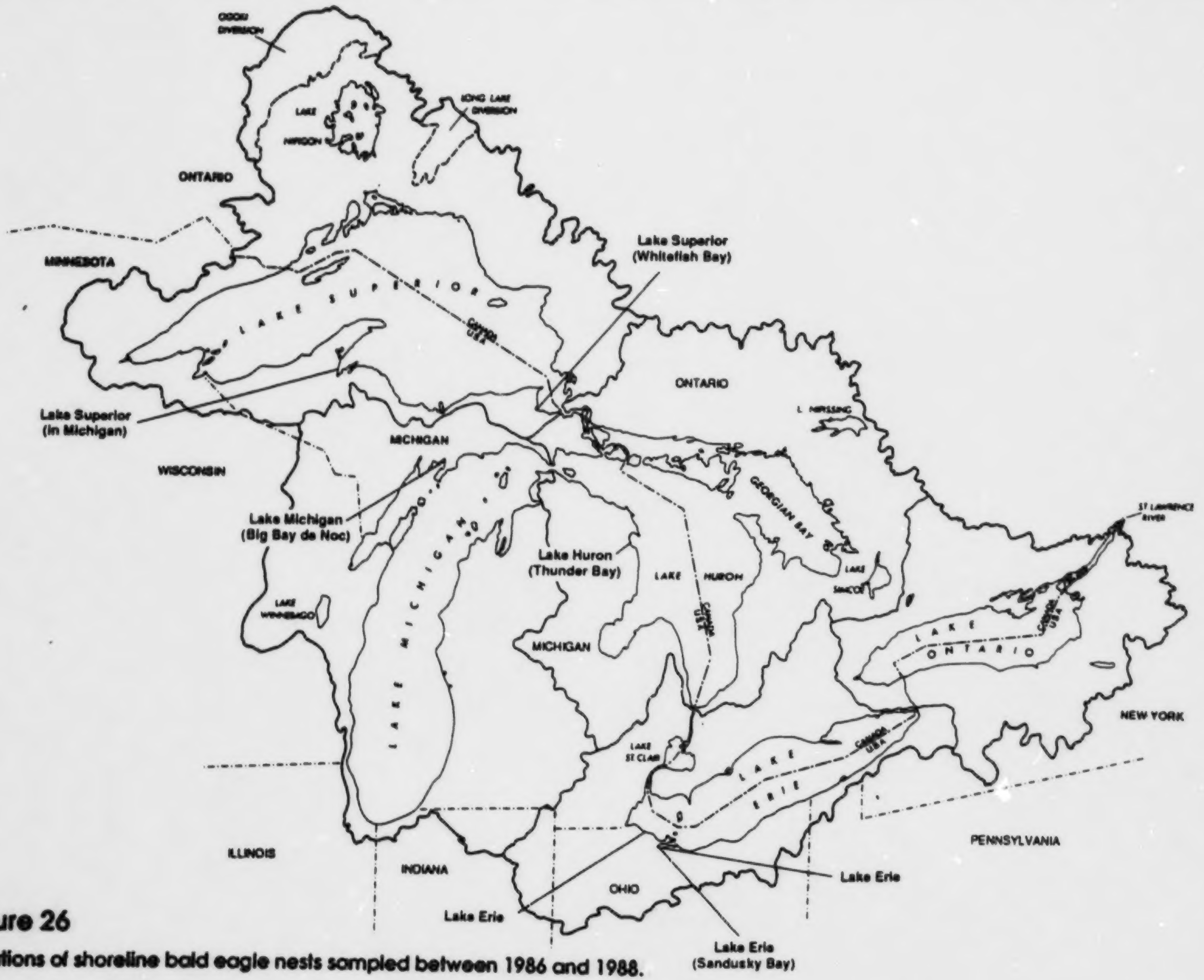
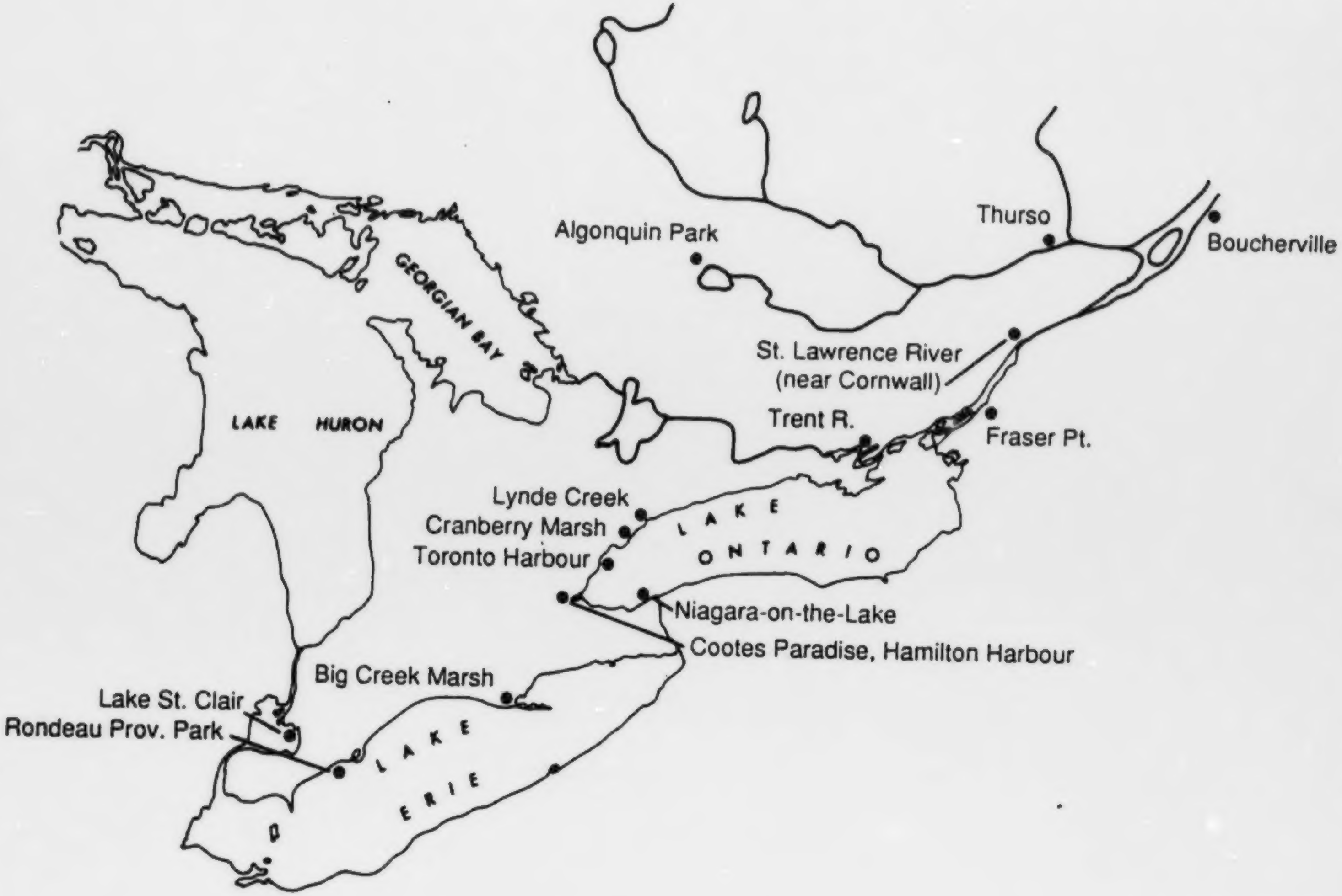

OGOKI DIVERSION
LAKE NIPIGON
LONG LAKE DIVERSION
ONTARIO
MINNESOTA
LAKE SUPERIOR
CANADA USA
Lake Superior (Whitefish Bay)
ONTARIO
L. NIPISSING
Lake Superior (In Michigan)
MICHIGAN
WISCONSIN
GEORGIAN BAY
ST LAWRENCE RIVER
Lake Michigan (Big Bay de Noc)
LAKE MICHIGAN
Lake Huron (Thunder Bay)
LAKE HURON
LAKE SIMCOE
LAKE WINNEBAGO
CANADA USA
LAKE ONTARIO
CANADA USA
MICHIGAN
NEW YORK
LAKE ST CLAIR
LAKE ERIE
CANADA USA
ILLINOIS
INDIANA
PENNSYLVANIA
Lake Erie
OHIO
Lake Erie
Lake Erie (Sandusky Bay)

Figure 26

Locations of shoreline bald eagle nests sampled between 1986 and 1988.

Source: D. Best U.S. Fish and Wildlife Service, unpublished data.
Note: See Table 9 for contaminant values for these locations.



Algonquin Park
Thurso
Boucherville
St. Lawrence River
(near Cornwall)
Trent R.
Fraser Pt.
GEORGIAN BAY
LAKE HURON
Lynde Creek
Cranberry Marsh
Toronto Harbour
LAKE ONTARIO
Niagara-on-the-Lake
Cootes Paradise, Hamilton Harbour
Big Creek Marsh
Lake St. Clair
Rondeau Prov. Park
LAKE ERIE

Figure 27

Locations of collection sites for snapping turtle eggs (1981-1989).

Source: C. Bishop (Canadian Wildlife Service)

TOXIC CHEMICALS IN THE GREAT LAKES AND ASSOCIATED EFFECTS

VOLUME I PART 4

CONCENTRATIONS OF CONTAMINANTS IN HUMANS

EXECUTIVE SUMMARY

Over their lifetime, residents of the Great Lakes basin are exposed to hundreds of chemicals many of which come from outside the region. Toxic chemicals have been detected in samples of tissues from residents of the Great Lakes basin. The same chemicals have also been identified in air, food, water, sediments and other biota, such as fish and wildlife, in the Great Lakes basin. Their presence in human tissues and in the environment confirms that there is human exposure to and bioaccumulation of these chemicals.

This part of the report reviews the scientific data on human exposure to toxic chemicals and residue levels of the same chemicals in residents of the Great Lakes basin. Some data from other regions of Canada, the U.S. and other parts of the world have been included for comparative purposes.

The majority of non-occupational exposure to environmental contaminants is through food. The precise proportion depends on many factors, but for most toxic chemicals discussed in this report it ranges from 40% to nearly 100%. Most of the studies on exposures to toxic chemicals in food only address exposures for the average adult, and do not deal with infants and children. There have been relatively few studies on concentrations of contaminants in food grown and consumed in the Great Lakes basin.

Comparisons of Canadian data with studies from the U.S. show that between 1976 and 1978 the estimated daily intake of thirteen different chemicals was greater in Canada than in the U.S. The estimated daily intake of six additional chemicals was approximately the same in the two countries over the same time period.

The Ontario Ministry of the Environment has analysed samples of raw and treated drinking water and samples from distribution systems for a wide variety of organic and inorganic chemicals. In general, levels are below current guidelines. The most important route of exposure to toxic chemicals in water is ingestion. However, some evidence indicates that dermal absorption has been underestimated.

The OMOE has conducted monitoring of contaminants in air (OMOE, 1988). Data on inorganics indicate that levels of lead in ambient air decreased by approximately 60% between 1977 and 1982. This has been attributed to the decreased use of leaded gasoline.

Exposure to lead in soil is particularly important for infants and children, who inadvertently consume large amounts of soil relative to other age groups. Kimbrough *et al.* (1984) have estimated that children between 18 months and 3 years old can ingest as much as 10 g/day. Although soils have been analysed for metals, concentrations are dependent on local soil conditions. Soils from Essex County have been analysed for PCBs.

Many toxic chemicals in the Great Lakes basin bioaccumulate so that organisms at higher trophic levels have higher residue concentrations than those at lower trophic levels. Humans, who are at the top of the food web, have relatively high concentrations in their tissues. Tissues containing the highest concentrations of toxic chemicals may not contain the largest proportion of the total body burden. For example, concentrations of organochlorines are higher in adipose tissue than in muscle, which has a lower lipid content. However, muscle tissue represents a larger proportion of the body mass than adipose tissue, and may contain the greatest amounts of lipophilic contaminants.

Residue levels have been measured in adipose tissue, blood, mothers' milk, kidney, liver, brain, muscle and gonads. There is most information available on adipose tissue, however, it is still insufficient to permit an assessment of spatial or temporal trends in residents of the Great Lakes basin. Nevertheless, residents of the Great Lakes basin do not have higher concentrations of contaminants than residents of other regions of Canada. Levels of metals (especially lead) and PCBs have been determined in blood. It is difficult to compare concentrations reported in different studies because of the use of different procedures and methods.

Mothers' milk contains a relatively high proportion of fat so it also contains relatively high concentrations of lipophilic chemicals. Therefore, nursing infants are exposed to toxic chemicals. Although there are some data available on levels of contaminants in mothers' milk, they are insufficient to permit an assessment of temporal or spatial trends.

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LIST OF ABBREVIATIONS AND SYMBOLS

Abbreviation	**Description**
DOE	Department of the Environment
GC	gas chromatography
HCB	hexachlorobenzene
HCH	hexachlorocyclohexane
NC	not calculated
ND	not detected
OMAF	Ontario Ministry of Agriculture and Food
OMOE	Ontario Ministry of the Environment
PAH	polyaromatic hydrocarbons
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
ppb	parts per billion
ppm	parts per million
ppt	parts per trillion
SD	standard deviation
TCDD	tetrachlorodibenzodioxin
TCDF	tetrachlorodibenzofuran
ΣDDT	sum of DDT and its metabolites

1. INTRODUCTION

1.1 OVERVIEW

Over their lifetime, residents of the Great Lakes basin are exposed to hundreds of chemicals, many of which come from outside the region. Human exposure in the Great Lakes basin is of particular interest because of the high population density and the relatively large amount of industry.

Toxic chemicals have been detected in samples of tissues from residents of the Great Lakes basin. The same chemicals have also been identified in air, food, water, sediments and other biota, such as fish and wildlife, in the Great Lakes basin. Their presence in human tissues and in the environment confirms that there is human exposure to and bioaccumulation of these chemicals.

This part of the report reviews the scientific data on human exposure to toxic chemicals in the Great Lakes basin. Some data from other regions of Canada, the U.S. and other parts of the world have been included for comparative purposes. It also reviews the available information on residue levels of the same toxic chemicals in tissues from residents of the Great Lakes basin. Some data from residents of other regions of Canada have been included for comparative purposes.

1.2 COMMENTS ON METHODOLOGY

It is difficult to evaluate and compare the results of different studies on toxic chemicals because of methodological differences. Although a few provided recovery data (e.g., LeBel and Williams, 1986), most of the studies reviewed in this section did not provide sufficient methodological information, such as the efficiency of sample extraction. Similarly, although some authors stated that their analytical instruments were calibrated regularly, none presented details of such procedures. This is important for studies with a long duration because instrument performance can fluctuate over time, as can the quality of solvents, adsorbents and other materials. In addition, analytical standards can decay if they are not stored or prepared properly. This is particularly true for standards for dioxins, dibenzofurans, polynuclear aromatic hydrocarbons and pesticides, such as mirex, which degrade with exposure to light.

Few studies presented raw data, such as chromatograms. In most, the data were assessed by conducting trend analyses and by comparisons with other data in the study and data from other studies. Summary data were often presented using means and standard deviations. However, authors reporting means rarely stated how concentrations less than the minimum detection level were handled. They were often arbitarily assigned values of zero, some fraction of the minimum detection level, or were excluded from the calculation of the mean. These values distort the mean, especially when there is a high proportion of results below the minimum detection level. In any case, means and standard deviations are inappropriate for data which are not normally distributed. Many authors reported ranges, either in addition to or instead of means and standard deviations. While ranges are a useful statistic, it is difficult to compare them because the distribution is not taken into account. In cases where data can be modelled by a log normal distribution, the geometric mean and/or median may be better descriptors of overall trends.

Many of the problems associated with the interpretation of data result from the inappropriate use of parametric statistical methods. To resolve this difficulty it would be better to provide information on the total number of samples, the number of samples with concentrations below the minimum detection level, the minimum detection level, as well as the range and frequency distribution or percentiles for values above the minimum detection level. These statistics would take into account all values and do not require the assumption of normally distributed data.

There are special problems associated with analyses for PCBs. Since the late 1960s, gas chromatography has been used to analyse samples for PCBs. However, different standards have been used in different studies. The two most commonly used standards are Aroclors 1254 and 1260. But because these PCB mixtures have different compositions, results obtained using one standard cannot be compared to results using the other. Furthermore, supposedly identical standards obtained from different sources can have different compositions (K.D. Nicol, personal communication).

2. PATHWAYS OF HUMAN EXPOSURE TO TOXIC CHEMICALS

2.1 FOOD

The majority of non-occupational exposure to environmental contaminants is through food. The precise proportion depends on many factors, but for most toxic chemicals discussed in this report it ranges from 40% to nearly 100%.

There have been several studies on pesticide residues in the average Canadian diet (Smith, 1971; Smith *et al.*, 1972; Smith *et al.*, 1973; Smith *et al.*, 1975; McLeod *et al.*, 1980). Unfortunately, several of these studies looked at samples from different regions in different years, making any trend analysis difficult. The most comprehensive study was McLeod *et al.* (1980). This study examined residue levels in five Canadian cities between 1976 and 1978. Since samples were collected simultaneously, residue levels can be compared between the cities. However, the definition of the average Canadian diet and the range of analytes differed from those used in other studies in the series making other comparisons difficult. The data from these studies on the Great Lakes basin are summarized in Table 2.1a.

Several studies on metal concentrations in the Canadian diet were conducted concurrently with the survey of pesticide residues in the Canadian diet mentioned above (Méranger and Smith, 1972; Kirkpatrick and Coffin, 1974; Kirkpatrick and Coffin, 1977). These are summarized in Table 2.1b. Sampling methods, locations and definition of diet were the same as those used in the pesticide surveys resulting in the same problems in making comparisons.

Recently, Davies (1988) and the Joint OMAF/MOE Toxics in Food Steering Committee (1988) analysed residue levels in foods available in Toronto and Ontario, respectively. The definition of "average diet" differed between the two studies, as well as within them. For example, Davies used the average annual consumption of partly skimmed cows' milk (66.2 L containing about 2 percent fat) to calculate the exposure of Toronto residents while she based her exposure estimates for Ontario residents on an annual consumption of 23.62 L of whole cows' milk (containing about 3.8 percent fat). Both of these estimates were referenced to a Statistics Canada report on family food expenditure in Canada (1982). It would have been more informative to make exposure estimates for both types of milk for both populations.

The Joint OMAF/MOE Steering Committee used two sources (an unpublished food processor's survey and a report entitled "The Apparent per Capita Domestic Disappearance of Foods in Canada" [Dominion Bureau of Statistics, 1966]) to select the food groups for analysis, yet it used a Nutrition Canada 24 hour food consumption recall survey (1977) to estimate exposure levels of dioxins and dibenzofurans. However, exposure via dairy products was not considered for HCB, PCBs or PCP. According to McLeod *et al.* (1980) dairy products account for the majority of exposure to HCB. These differences in definition lead to considerable differences in calculated daily intake and make comparison difficult, if not impossible.

Most of the studies on exposures to toxic chemicals in food only address exposures for the average adult, and do not deal with infants and children. Since the diets of infants and children differ from those of adults, it is not possible to directly extrapolate exposures from adults to children. For example, between 1 and 4 years of age children consume about 680 g of milk and dairy products daily. This is equivalent to about 50% of their total food intake. Adult males aged 20 to 39 years consume about 454 g of milk and dairy products daily. This is equivalent to about 25% of their total food intake (Nutrition Canada, 1977). Therefore, children not only have a greater daily intake of lipophilic contaminants from milk and dairy products, but also on a body weight basis their daily intake is nearly five times greater than that of adult males. Gartrell and co-workers (1986a, 1986b) estimated the daily intake of pesticides, elements, and other chemicals in infant, toddler and adult diets and found that exposure levels varied between age groups. For example, daily lead intakes were estimated to be 2.43, 2.22, and 0.59 μg/kg bw for infants, toddlers, and adults, respectively. These differences are especially important because chemicals such as lead are absorbed from the gastrointestinal tract at a greater rate in children than in adults (Jaworski, 1979).

There have also been several studies on exposure to dioxins and furans in foods. The Joint OMAF/MOE Toxics in Food Steering Committee (1988) and the Federal-Ontario Ad Hoc Working Group on Multimedia Standards (unpublished) have estimated that the exposure levels of the average Canadian to dioxins and furans respectively are 1.52 and between 0.6 and 2.3 pg 2,3,7,8-TCDD equivalents/kg bw/day.

Studies on contaminant residues in food have also been conducted in the U.S. Comparisons of these studies with the Canadian data show that between 1976 and 1978 the estimated daily intake of thirteen different chemicals was greater in Canada than in the U.S. The estimated daily intake of six additional chemicals was approximately the same in the two countries over the same time period. The estimated intake of dicofol was greater in Canada than in the U.S. (McLeod *et al.*, 1980; Gartrell *et al.*, 1985). The estimated daily intake of PCBs in the Toronto area in 1985 was greater than that in the U.S. in 1981/82, while the intakes for all other chemicals examined were similar (Davies, 1988; Gartrell *et al.*, 1986b).

2.2 DRINKING WATER

The Ontario Ministry of the Environment has analysed samples of raw and treated drinking water and samples from distribution systems for a wide variety of organic chemicals. Since a survey by Armstrong and coworkers (1981) suggested that over 80% of Canadians "usually" flush the tap prior to use, free-flow values from the OMOE (1987) report are the most appropriate to predict exposures from drinking water. This procedure has been recommended because lead is often detected in 'first flush' water in houses with lead service connections or in which lead solder has been used. The data are summarized in Table 2.2a. They show the locations where the highest levels of toxic chemicals were detected.

In 1986, the Canadian Public Health Association conducted a survey of drinking water data from the Canadian side of the Great Lakes. Since there was a high frequency of values below the minimum detection levels, drawing conclusions from positive data would result in overestimation of the mean levels of contaminants.

The most important route of exposure to toxic chemicals in water is ingestion. However, some evidence indicates that dermal absorption has been underestimated. For example, Brown *et al.* (1984) estimated that the non-occupational dermal route accounts for between 29 and 91% of total exposures for toluene, ethylbenzene and styrene. Other possible exposure routes are steam inhalation during bathing or food preparation and eating of food prepared with contaminated water.

Water hardness may influence exposures to toxic chemicals in drinking water. For example, Neri (1976) has reported that the daily intake of chromium varies from 0.6 ng in soft water areas to 4.1 ng in hard water areas.

2.3 AIR

The OMOE has conducted monitoring of numerous contaminants in air (OMOE, 1988). However, this has focused on conventional pollutants such as NOx and SOx and there are few data available on levels of the persistent contaminants discussed in this report. Data on inorganics indicate that levels of lead in ambient air decreased by approximately 60% between 1977 and 1982. This has been attributed to the decreased use of leaded gasoline. Between 1982 and 1986, lead levels in ambient air remained relatively constant. Between 1977 and 1986, copper levels decreased by approximately 30% (see Table 2.3c).

Data on organic chemicals in air collected by the Detroit Incinerator Monitoring Program is representative of the quality of work needed to monitor ambient air quality (DOE, 1988b). Detailed descriptions of sampling methodologies, extraction procedures and detection limits are important aspects of any air monitoring program.

Mean total PCB levels in air have increased slightly between those reported for the Great Lakes basin for 1966 to 1981 (Eisenreich *et al.*, 1981) and those reported for Windsor in 1987 (DOE, 1988b) (see Table 2.3d).

2.4 SOIL

Exposure to lead in soil is particularly important for infants and children, who inadvertently consume large amounts of soil relative to other age groups. Kimbrough *et al.* (1984) have estimated that children between 18 months and 3 years old can ingest as much as 10 g/day. Between the ages of 3 and 5 years, the amount gradually decreases to approximately 100 mg/day.

In Ontario, mean natural background levels of lead in agricultural soils (i.e., agricultural soils which have not been treated with lead arsenate) was

14.1 ppm (Frank *et al.*, 1976). Weis and Barclay (1985) reported that the concentration of lead in Essex County soils was 12.0 mg/kg and 44.8 mg/kg in urban Windsor soil. The Ontario blood lead study (City of Toronto Medical Officer of Health, 1987) found lead concentrations in urban and non-urban soil to be 47 and 22 ppm, respectively. The same study reported that soil from South Riverdale contained 641 ppm of lead. These figures are geometric means. The South Riverdale site is adjacent to a secondary lead smelter and has more local gas stations than the other urban and non-urban sampling locations.

Concentrations of arsenic, mercury and copper in agricultural soils treated with pesticides, trace elements, fertilizers, feed additives and other non-agricultural additions such as sewage sludge, can be higher than those in untreated soils (Frank *et al.*, 1976). However, because most people reside on non-agricultural land, levels in agricultural soil do not predict exposures to the general population accurately.

Concentrations of cadmium, chromium and nickel are not affected by agricultural practices (Frank *et al.*, 1976). The mean concentration of cadmium in 69 samples of agricultural soils has been reported as 0.56 ± 0.69 ppm. Levels of cadmium in Dayton, Ohio averaged 1.65 ppm (Ritter and Rinefierd, 1983). Cadmium concentrations in soil from Windsor and Essex County have been reported as 0.62 ± 0.07 mg/kg and 0.38 ± 0.02 mg/kg, respectively.

Determining ambient levels of metals in soils is very difficult. Frank *et al.* (1976) found that concentrations of most metals in Ontario soils increase with increasing clay or organic content. Since different types of soil have different metal concentrations, there is no representative ambient level. Local soil conditions are more relevant to estimate local human exposure.

Soil samples from Essex County were also analysed for PCBs. Concentrations of PCBs, as Aroclor 1260, in 37 samples averaged 3.58 ± 1.04 μg/kg, at a minimum detection level of 3 μg/kg. The percentage detection was 34.2%. PCBs, as Aroclors 1254 and 1242, were detected in only 10.8 and 5.4% of the samples, respectively. Near Windsor, the mean PCB concentration in soil was reported as 13.17 ± 4.81 μg/kg.

3. HUMAN TISSUE DATA

Many toxic chemicals in the Great Lakes basin bioaccumulate so that organisms at higher trophic levels have higher residue concentrations than those at lower trophic levels. Humans, who are at the top of the food web, have relatively high concentrations in their tissues.

Baseline levels of selected toxic organic and inorganic chemicals in human tissues and fluids, including adipose tissue, milk and blood, are available. These levels should refer to tissue concentrations in the general population and should not include individuals that have had known occupational or acute chemical exposures. Although the data included in this review apparently satisfied this requirement, it was rarely addressed explicitly. This report does not address occupational and acute exposures.

It does consider concentrations of toxic chemicals in blood (and blood fractions), milk and adipose tissue. The organic chemicals of interest are lipophilic (fat soluble) and, therefore, they are studied in tissues or fluids that are relatively rich in fat, such as adipose tissue and milk. Metal concentrations have been studied in blood, liver and kidney. Where appropriate, data on these tissues are presented.

Tissues containing the highest concentrations of toxic chemicals may not contain the largest proportion of the total body burden. For example, concentrations of organochlorines are higher in adipose tissue than in muscle, which has a lower lipid content. However, muscle tissue represents a larger proportion of the body mass than adipose tissue, and may contain the greatest amounts of lipophilic contaminants (Geyer *et al.*, 1986; Ryan *et al.*, 1985b).

In some cases, the relative levels of residues in different tissues may provide information on the individual's exposure history. High levels of organochlorines in the blood may indicate relatively recent exposure or reflect recent changes in metabolism, but may not be a predictor of the total body burden. On the other hand, residues in adipose tissue are more stable over time, and are considered to be representative of historical exposure and body burden.

3.1 ADIPOSE TISSUE

Adipose tissue is found throughout the human body, and is made up of areolar (connective) tissue and fat cells (Gray, 1974). On average adipose tissue constitutes 15% of body weight, although the proportion can range from 2% to 50% of body weight (Mountcastle, 1974). Adipose tissue contains relatively high levels of lipophilic contaminants because it contains the highest lipid concentration in any tissue.

The lipid content of adipose tissue has been reported as 81.4 ± 11.0% (Mes *et al.*, 1977). In another study, the lipid content in adipose tissue of abdominal origin ranged from 66% to 102%. The mean was 90% (Ryan *et al.*, 1985). This variability makes it difficult to compare levels of toxic chemicals on a wet weight basis. Only two studies have reported the residue levels on a lipid basis (Holdrinet *et al.*, 1977; Kadis *et al.*, 1970).

Data on toxic chemicals in human adipose tissue are presented in Tables 3.1a to 3.1u. The means were converted to standardized units for comparative purposes.

The tables show levels of toxic chemicals in adipose tissue from residents of the Canadian Great Lakes basin and other regions of Canada. The national Canadian data include data from Ontario. This overlap may contribute to the similarity in levels between Canada and Ontario. Mes and coworkers conducted two national surveys of residue levels in adipose tissue (Mes *et al.*, 1977; Mes *et al.*, 1982). In 1972, mean levels of PCBs, p,p'-TDE, dieldrin, and ß-HCH were highest in Ontario samples, compared to those from residents of other regions, although the differences were probably not significant (Mes *et al.*, 1977). A comparison of p,p'-DDT data in Table 3.1f suggests that Ontario residents had lower mean levels than other Canadians. In 1976, although the mean level of PCBs (using an Aroclor 1260 standard) in Ontario samples was higher than that for total Canadians, the levels were similar when an Aroclor 1242 standard was used (Table 3.1u; Mes *et al.*, 1982). There are insufficient data to permit an assessment of temporal or spatial trends of residue levels in adipose tissue. However, based on the limited data available, residents of the Great Lakes basin do not have higher concentrations than residents of other regions in Canada. There are differences within Ontario and Canada that probably reflect local exposures.

Most of the studies on levels of toxic chemicals in adipose tissue use samples taken from cadavers. Some sampled cadavers randomly, without regard to the cause of death (Williams *et al.*, 1984; Kadis *et al.*, 1970; Frank *et al.*, 1988; Williams *et al.*, 1988; Holdrinet *et al.*, 1977), while others restricted the study population to persons who died accidentally (Ritcey *et al.*, 1973; Brown, 1967; Mes *et al.*, 1977; Mes *et al.*, 1982; Ryan *et al.*, 1985). Age, sex, or exposure histories were not consistently reported. Time between death and sampling and conditions of storage of cadavers were not documented in any of the studies reviewed. It is unclear how these factors could affect tissue concentrations.

Half (5/10) of the adipose tissue studies mentioned in this report do not state the anatomical origin of the samples. This can make interpretation difficult if there are differences in the concentrations of fat or in the rates of fat metabolism in adipose tissue from different locations in the body. Lipid composition in mammals, such as polar bears, varies with the anatomical location and the condition of the individual (M. Cattet, personal communication).

There may also be significant differences between levels of toxic chemicals in samples from men and women (Mes *et al.*, 1977; Mes *et al.*, 1982; Williams *et al.*, 1984). These differences probably reflect differences in the lipid content of adipose tissue because women have a greater proportion of fat in adipose tissue than men (Vague and Fenasse, 1965). In contrast, Frank and coworkers (1988) reported residue levels in human adipose tissue on a lipid basis and found no differences between males and females.

The statistical methods used in studies of adipose tissue are often inappropriate. All of the studies reported mean levels, but only two (Williams *et al.*, 1984; Williams *et al.*, 1988) described how they were calculated and how they dealt with results below the minimum detection limit. If Mes and coworkers (1977, 1982) had calculated the mean using only the positive values, as they did in their studies on mothers' milk (Mes and Davies, 1979; Mes *et al.*, 1986; Davies and Mes, 1987), it would have been overestimated. Mean and standard deviations may not be the most appropriate statistics to report. Williams and coworkers (1984, 1988) recognized that their data were not normally distributed, and the data plotted by Holdrinet *et al.* (1977) do not describe a normal distribution. In these situations, the arithmetic mean is not a good description of contaminant levels.

3.2 BLOOD

Blood is not often used for determining long term exposure to lipophilic substances, but it has been used to monitor acute and occupational exposures to organic chemicals. Blood has the advantages of being readily available and well characterized. It has been widely used to determine human exposure to metals, such as lead.

Data on residue levels in human whole blood and blood components are shown in Tables 3.2a to 3.2d. The reported means were converted into standardized units so that they can be compared. The standardized means for whole blood were converted to units on a weight by weight basis to allow comparisons with other tissues.

In 1977, the mean concentrations of copper, cadmium and lead in whole blood from children living in British Columbia were 1.05, <0.0005 and 0.115 µg/g, respectively (Subramanian and Méranger, 1983). Corresponding levels in U.S. children were 1.23, 0.25 and 0.157 µg/g, respectively (year not stated) (Smith *et al.*, 1976). Thus, U.S. children may have higher concentrations of metals in blood than those from British Columbia. Ontario children sampled in 1984 had lead levels in whole blood similar to those found in children in British Columbia in 1977 (Macpherson, 1987).

Serum nickel levels in samples taken in 1971 from residents of Sudbury, Ontario and Hartford, Connecticut were compared by McNeely and co-workers (1972). These results suggest that nickel concentrations in serum from Sudbury residents were almost double (mean 4.6 µg/L) those of Hartford residents (mean 2.6 µg/L). An international study of nickel in adults examined serum samples collected between 1956 and 1971 (Iyengar *et al.*, 1978). The reported mean nickel concentration in these samples was 29.7 µg/L. Iyengar and Woitteiz (1988) reported a median serum nickel concentration of 0.2 µg/L (range <0.05 - 1.3 µg/L).

In these studies, blood was generally collected by venipuncture or heelstick (infants). Some studies reported data for plasma or serum, rather than for whole blood (McNeely *et al.*, 1972; Versieck, 1985). Plasma is prepared by drawing blood into a vessel containing an anticoagulant and then removing the red blood cells by centrifugation. Serum is prepared by allowing whole blood to clot and then centrifuging the remaining liquid to remove blood cells (e.g., McNeely *et al.*, 1972). Therefore, the major difference between plasma and serum is that the clotting proteins are present in the former, but largely eliminated from the latter. Whole blood, serum and plasma differ from each other in the relative amounts of protein, fat and other components. Therefore, concentrations of toxic chemicals cannot be directly compared between them. It is common to analyse the blood fraction containing the highest proportion of specific chemicals. For example, lead is usually analysed in whole blood, while copper is usually studied in serum or plasma (Subramanian, 1986).

Pre-sampling factors are events associated with a biological specimen *in situ*, before its arrival at the laboratory for analysis (Iyengar, 1982). They can include genetic, environmental and dietary factors and post mortem changes. Both dietary and environmental factors are important in determining tissue levels of metals such as arsenic, cadmium, manganese, lead, selenium and zinc (Iyengar, 1984). Tissue levels of metals often differ significantly in populations from urban and rural areas. The City of Toronto (1987) identified four factors that affected blood lead levels in children. These were the proximity to industry, local traffic density, socio-economic status and soil lead levels in the immediate environment. Blood levels of cadmium can be elevated by smoking (Iyengar, 1982). Therefore, study populations should include smokers in the same proportion as in the general population, if the representative results are needed. Other environmental and physiological factors that are important in sample selection include pregnancy, lactation, age, gender, seasonal variations, geographical location (Iyengar, 1982).

Concentrations of PCBs in blood increase with age (Kimbrough, 1985). This study also reported lower blood levels of total PCBs in women than in men. After death, changes in organ volume, cell swelling and autolysis occur. These processes can result in changes in metal profiles (Iyengar, 1981).

Some authors reported that following sampling (and preparation for serum or plasma) tubes containing blood were immediately capped and stored at -10°C until analysis (McNeely *et al.*, 1972; Subramanian and Méranger, 1983). However, other authors did not provide details of sample collection and storage (e.g., Smith *et al.*, 1976; Wheatley, 1979; Wheatley, 1984; Macpherson, 1987).

Quality control is difficult for analyses of metals in blood. Several different analytical methods have been used. It is difficult to measure concentrations accurately because metals exist in several physiochemical states in blood (e.g., in solution, adsorbed to protein in solution and bound to protein in cells). It is not reasonable to assume that the metal in a "spiked" blood sample (i.e., to be used as a standard) will be in the same physical form as metal in test samples (Subramanian and Méranger, 1983). When biological materials are analysed for trace elements by graphite furnace atomic absorption spectrometry, matrix interferences can be significant, especially in the absence of stabilized temperature platform furnace atomization (Subramanian, 1986). Comparison of metal concentrations determined by different methods is thus extremely difficult. This problem is often aggravated by poor documentation and inconsistent application of quality control measures.

Sometimes authors reported recoveries for metals (e.g., McNeely *et al.*, 1972; Smith *et al.*, 1976; Subramanian and Méranger, 1983), although they did not state whether data were corrected for recoveries. When authors did report recoveries, they were usually close to 100%. Other authors did not mention recovery efficiency (Wheatley, 1979; Wheatley, 1984; Macpherson, 1987). Subramanian and Méranger (1983) analysed a lead standard and obtained a value of 236.5 ng/mL. This was in close agreement with the expected value of 228 ng/mL.

In the City of Toronto study of blood lead levels (1987) there was a change of analytical laboratories between 1982 and 1983, but the authors did not state whether a comparison of the laboratories was undertaken. A small study was done between the laboratory used in 1983 and another facility. The results showed significant correlation (r=0.67, p<.01).

Blood levels of chemicals reflect only the circulating portion of the total body burden for any chemical, and do not indicate the proportion or concentrations in other tissues. They reflect recently ingested chemicals which have not yet been distributed to other tissues, as well as chemicals released from other tissues. For example, mobilization of lipids may result in increased blood levels of lipophilic chemicals (Geyer *et al.*, 1986). However, Murphy and Harvey (1985) concluded that residues of some pesticides and their metabolites in various tissues and fluids are indicative of the total body burden, and of past and present exposures. PCB levels can increase dramatically one hour after the ingestion of PCB-contaminated food, such as fish from the Great Lakes, peak ten hours after the meal and return to baseline values within one week as the PCBs are moved out of the blood and into the tissues. Kimbrough (1985) has reviewed articles which postulated that the congener-specific composition of PCBs must be known to correlate exposures with health effects. Total PCB levels in serum or tissues may not have much predictive value to assess health effects.

Baseline concentrations of metals in human tissues exhibit considerable variation. These are described in an extensive compilation by Iyengar and coworkers (1978), and Iyengar (1984). Inappropriate analytical techniques are likely to affect the accuracy of the results, although Versieck (1985) found that the accuracy and precision of the data were more dependant on the analyst than on the techniques employed. Furthermore, contamination of sample collection equipment is a common source of experimental error. Use of metallic needles, rubber lids on collection tubes and dirty glassware can contaminate samples and lead to inaccuracies.

Baseline values for blood lead levels are disputed. Iyengar *et al.* (1978) described results of 20 studies of lead levels in human whole blood published before 1976. The review reported a mean (based on the reviewed work) whole blood lead concentration of 0.214 mg/mL. Versieck (1985) indicated that levels of lead in plasma have probably been overestimated significantly, and that improved sample handling and analytical procedures are necessary.

Mes (1987) found that Toronto children (aged between 2 and 5 years) that had been exposed to PCB-contaminated soil had mean PCB blood levels of 0.54 ng/g (range 0.22 - 0.99) compared to a mean of 0.88 ng/g (range 0.28 - 2.30) in the non-exposed group. This difference was not statistically significant. The mean blood lipid content in both groups was 0.15%. Congener-specific data are reported in Mes (1987).

In addition to the above difficulties, baseline levels of metals in blood from children and adults may not always be equivalent (Henkin *et al.*, 1973; Versieck, 1985). Most baseline values are based on analysis of samples from adults. Therefore, appropriate baseline concentrations and acceptable levels should be used when considering the health implications of metal exposures in children.

An extensive study of methylmercury levels in Canadian native people across Canada (Wheatley, 1979 and 1984), started in the mid-1970s, showed that a number of Indian people resident in the Great Lakes basin were reaching blood mercury levels in the "increasing risk" range (20-99 ppb). These levels were similar to findings among Indian residents of a number of other communities elsewhere in Canada. They did not reach the "at risk" levels (over 100 ppb) found in residents of other Ontario native communities known to be highly exposed to mercury contamination (e.g. Grassy Narrows and Whitedog) nor certain Quebec Indian communities (e.g. Mistassini and Waswasipi).

3.3 MOTHERS' MILK

Mothers' milk contains a relatively high proportion of fat so it also contains relatively high concentrations of lipophilic chemicals. Therefore, nursing infants are exposed to toxic chemicals.

Data on residues of toxic chemicals in mothers' milk are shown in Tables 3.3a to 3.3s. Locations in the Canadian Great Lakes basin are listed first, followed by other regions in Canada. Results are shown chronologically. The Canadian data include data from Ontario residents so there is some overlap. The reported mean was converted to standardized units to facilitate comparisons.

There have been three national surveys of residues in human milk. One in 1967 (Ritcey *et al.*, 1972), one in 1975 (Mes and Davies, 1979), and one in 1982 (Mes *et al.*, 1986). All of these studies reported residue concentrations on a whole milk basis. However, data are best reported on a milk fat basis. This makes comparisons easier. Only Ritcey *et al.* (1972) also reported comparison results on a lipid basis.

Mes and Davies (1979) concluded that PCB and DDT levels in samples taken in 1975 were highest in Ontario, Alberta, and British Columbia, compared to other regions of Canada. In the 1982 survey, Mes and coworkers (1982) stated that there were minimal differences in residue levels between different regions of the country. However, no statistical comparisons were conducted in either study.

Mes and co-workers (1986) compared residue levels over the same time period in samples of Canadian mothers' milk (on a fat basis) with samples from other western countries (U.S., Great Britain, Germany and Sweden). Levels of p,p'-DDE and p,p'-DDT were lower in the Canadian samples. Concentrations in the Canadian samples were mid-range for all other chemicals for which data were available from all five countries.

Comparisons of residue levels between different regions are hindered by the variability of methods used to report data. For example, different regions appear to have the highest levels of ΣDDT, depending on the method used to present the results. On a whole milk basis, Ontario has the highest mean level but Alberta and British Columbia have the highest mean levels on a milk fat basis, and Saskatchewan and Manitoba have the greatest concentration ranges (Ritcey *et al.*, 1972). No statistical analysis was done in this study to determine whether differences between regions were significant.

Some studies reported that samples were manually expressed (Davies and Mes, 1987; Mes *et al.*, 1986; Dillon *et al.*, 1981), while others reported the use of breast pumps for sample collection (Currie *et al.*, 1979). Occasionally, both sampling methods were used in a single study (Mes and Davies, 1979; Musial *et al.*, 1974). The use of breast pumps could result in contamination of the sample with organic chemicals from the plastic or rubber components. This possibility was not investigated.

The time of day and the state of the breast when samples are taken are also important. Single samples taken randomly throughout the day will not necessarily be representative of residue levels. For example, Wilson *et al.* (1973) found that ΣDDT concentrations were significantly higher in hind-milk (that is from a nearly empty breast) as opposed to fore-milk (that is from a full breast). A similar study by Mes and Davies (1978) found that both fat and residue levels increased over a feeding period. Fat content and residue levels not only varied within a feeding, but they also varied between feedings, and during lactation by the same individual. Mes (1981) suggested that the most representative sample would be a composite comprised of samples from each feeding in a given day, from different times within a feeding, and alternately from the right and left breasts.

Mes and Davies (1978) measured the diurnal patterns in milk fat and organochlorine levels in two women. During a single day, milk fat levels in the two women ranged from 0.55 to 4.69% and from 0.54 to 3.63%. Jensen (1983) stated that the fat content is the most variable component of milk. This suggests that data for lipophilic compounds should be reported on a lipid basis to provide an indicator of body burden. However, results reported on a whole milk basis are more valuable when determining total infant exposure (Jensen, 1983). While there is not a strict linear relationship between residue levels and fat concentrations, the range of residue levels on a lipid basis is usually smaller than that for whole milk (Mes and Davies, 1978).

To obtain valid population-based data on residues in mothers' milk it would be necessary to get representative samples from the population of lactating women, as well as representative samples from each individual. Residues of some toxic chemicals increase with the age of the mother, though this trend may be reversed if the woman has breast-fed a previous child (Dillon *et al.*, 1981; Wilson *et al.*, 1973). Residues, such as PCBs, have been shown to be higher in urban residents than in rural residents (Dillon *et al.*, 1981; Frank *et al.*, 1988). Other factors such as consumption of freshwater fish and smoking also affect milk residue levels. This type of information should be documented to avoid biased sample populations.

3.4 OTHER TISSUES

A few authors have reported concentrations of toxic chemicals in human kidney and liver. Data on metals in samples from residents of the Great Lakes basin are shown in Tables 3.4a and 3.4b. Concentrations of lipophilic organic chemicals in samples of liver from residents of Alberta are presented in Tables 3.4c and 3.4d.

Kadis and co-workers (1970) reported levels of insecticides in extractable lipids of different human tissues. They found that levels were highest in adipose tissue, followed by liver, kidney, gonads and brain in decreasing order. Similarly, Ryan *et al.* (1985b) found that wet weight concentrations of dioxins and furans in human tissues were highest in adipose tissue, followed in descending order by liver, muscle and kidney. However, this study found that residue levels measured on a lipid basis were similar for all tissues. Since the geographic origin of the tissue samples was not stated, the data from Ryan *et al.* (1985b) were not included in the tables.

Méranger *et al.* (1981) compared levels of cadmium in samples of Canadian kidney cortex to those from a 1965-66 Swedish survey. For all age groups and both sexes, Canadian kidney samples had higher cadmium levels than those found in the Swedish study. For both populations, concentrations of cadmium in the kidney increased until about age 50 and thereafter decreased.

Subramanian and Méranger (1982) also reported concentrations of 20 metals in liver and kidney samples from the Great Lakes basin. The authors stated that their results indicated that there were higher levels of most metals in Canadian tissue samples than had been previously reported in Swedish subjects (Brune, Nordberg, and Webster, 1980, cited in Subramanian and Méranger 1982). In particular, concentrations of cadmium in liver and kidney samples were higher in the Canadian samples by factors of 5 and 20, respectively. However, the authors point out that the Swedish samples were from eight non-smoking individuals who lived in areas with "extremely low pollution density".

Subramanian *et al.* (1985) reported the levels of 20 metals in kidney (medulla and cortex) and liver samples taken after autopsy from hospitals in Ottawa and Kingston. There were differences in the tissue concentrations of copper, iron, potassium, magnesium, maganese, sodium, phosphorus, selenium and zinc between the samples from Ottawa and Kingston. No correlation between tissue concentrations and either sex or age was observed.

4. CONCLUSIONS

1. Residents of the Great Lakes basin are exposed to hundreds of chemicals over a lifetime, many of which come from outside the region. Some of these chemicals have been detected in adipose tissue, blood, mothers' milk, liver, kidney, brain, muscle and gonads. Their presence in the environment and in human tissues confirms that there is exposure and bioaccumulation.

2. The majority of non-occupational exposure to environmental contaminants is through food, much of which is grown outside the basin. The precise proportion depends on many factors but is between 40 and nearly 100% for the chemicals discussed in this report. Exposure through air, water and soil contribute smaller proportions, although exposure through soil is an important route for small children who inadvertently ingest large amounts.

3. The majority of exposure to environmental contaminants in food is from dairy products and meat. It is difficult to compare concentrations reported in different studies because of different definitions of 'average diets' and because samples have been analysed for different chemicals. Most of the studies on exposure from food are for an average adult and do not deal with infants and children, whose exposures are often larger (per unit body weight).

4. Although the data are very limited and different studies cannot often be compared, it is unlikely that residents of the Great Lakes basin are exposed to higher concentrations of contaminants than people living elsewhere in Canada.

5. Levels of contaminants in adipose tissue are indicative of body burdens, but there are insufficient data to permit an assessment of temporal or spatial trends. However, levels in residents of the Great Lakes basin are no higher than those in residents of other regions of Canada. Levels of metals, especially lead, and PCBs have been determined in blood. These reflect recent exposures. Concentrations of contaminants in mothers' milk are important because they indicate loadings to nursing infants. It is difficult to determine spatial and temporal trends because historic data are inadequate and there are differences in sample collection and analysis.

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Dr. Theo Colborn
World Wildlife Fund
The Conservation Foundation
Washington, D.C.

Dr. Kate Davies
Ecosystems Consulting Inc.
Orléans, Ontario

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PATHWAYS OF HUMAN EXPOSURE TO TOXIC CHEMICALS: FOOD

Table 2.1a Canadian and American Dietary Intake of Organic Chemicals[1]

Chemical	Ottawa 1969[2,3]	Toronto 1973[2,4]	Toronto 1976-78[2,5]	Toronto 1985[2,6]	U.S.A 1976-78[2,7,9]	U.S.A. 1981-82[2,8]	ADI FAO/WHO[2]	% Total Exposure[6]
HCH, total	0.035	0.032	0.016	0.004	0.012-0.015	0.010	10 (τHCH)	
Chlordane	-	-	<0.001	-	0.003-0.004	0.004	1 (0.006)	
DDT, total	0.270	0.058	0.021	0.033	0.046-0.070	0.034	5	99.9
Diazinon	-	0.002	0.004	-	0.004-0.006	0.007	2	
Dieldrin	0.057	0.025	0.009	0.011	0.017-0.041	0.016	0.1	99.2
Endosulfan	0.006	0.022	0.004	-	0.010-0.012	0.044	7.5 (4.0)	
Endrin	-	0.002	<0.001	-	ND-<0.001	ND	0.2	
Ethion	-	0.004	<0.001	0.001	0.001-0.018	0.005	5.0	
Heptachlor epoxide	-	0.004	0.001	-	0.006-0.008	0.007	0.5	100
Malathion	-	0.009	0.022		0.128-0.154	0.243	20	
Methidathion	-	-	0.006	-	-	ND	-	
Parathion	-	<0.001	<0.001	-	0.001-0.004	0.002	5.0	
Parathion, methyl	0.002	-	-	-	ND-0.001	0.001	1.0	
Phosalone	-	-	<0.001	-	0.001-0.017	0.024	6.0	
Toxaphene	-	-	<0.001	-	<0.001-0.107	0.023		
Captan	-	-	0.006	-	0.008-0.031	0.015	100	
Chlorothalonil	-	-	<0.001	-	-	-	30	
Dichloran	-	-	0.030	-	0.032-0.056	0.047	30	
HCB	-	0.072	0.002	<0.001	0.002-0.004	0.002	0.6	56.6
Quintozene	-	-	<0.001	-	0.002-0.003	0.007	7.0	
Chlorobenzilate	-	-	<0.001	-	-	0.002	20	
Dicofol	0.054	0.050	0.018	-	0.004-0.010	0.006	25	
Chlorpropham	-	-	0.083	-	0.088-0.310	0.347		
PCBs	-	-	0.011	0.012	<0.001-0.027	0.003		98.6

1. Based on an adult diet.
2. μg/kg-bw/day.
3. From Smith, 1971.
4. From Smith *et al.*, 1975.
5. From McLeod *et al.*, 1980.
6. From Davies, 1988.
7. From Gartrell *et al.*, 1985
8. From Gartrell *et al.*, 1986b
9. Range of estimated values for that time period.

7. APPENDIX: DATA TABLES

Table 2.1b Canadian Dietary Intake of Inorganic Chemicals[1,3]

Chemical	Dietary Intake µg/person/day	Dietary Intake µg/kg-bw/day	% Absorption	Nutritional Requirement µg/person/day	ADI µg/kg-bw/d	% Total Exposure
Arsenic	25-95	0.4-1.4	6			
Cadmium	52-80	0.7-1.1	3-7		0.8-1.0	
Chromium	136-284	1.9-4.1			1.4	
Cobalt	36-102	0.5-1.5		<100		
Copper	1,606-2,217	22.9-31.7		1,000-3,000		
Iron	15,418-19,443	220-278		12,000-15,000		
Lead	77-148	1.1-2.1	8-10 (Adult) 25-53 (Child)		7.1 Adult 3.6 Child	40-50
Manganese	2,930-4,091	41.9-58.4		3,000-5,000		
Mercury, total	10-16	0.1-0.2				
Mercury, inorganic					0.71	
Mercury, organic			90		0.47	
Nickel	347-576	5.0-8.2	1-10	<20[2]	85.7	
Zinc	15,236-19,863	218-284		10,000-20,000		

1. Based on an adult diet.
2. Assumed dietary requirement, exact level unknown.
3. From: Jaworski, 1979;
   Jaworski, 1980;
   Kirkpatrick and Coffin, 1974;
   Kirkpatrick and Coffin, 1977;
   Meranger and Smith, 1972; and
   Smith, 1971.

PATHWAYS OF HUMAN EXPOSURE TO TOXIC CHEMICALS: DRINKING WATER

Table 2.2a Residue Levels and Location of Highest Value in Drinking Water: Organics (from OMOE, 1987)

Chemical Name	N	MDL[1] (ng/L)	Number of positives	Location of highest concentration
PCBs	1020	20	0	
α-chlordane	1202	2	0	
τ-chlordane	1202	2	0	
OCS	1202	1	0	
p,p'-DDT	1207	5	1	Cornwall (5 ng/L-trace)
p,p'-DDE	1186	1	3	Ottawa (Britannia) (2 ng/L)
τ-HCH	1038	1	216	Brantford (11 ng/L)
Mirex	1147	5	1	Belleville (5 ng/L)
1,2-DCB	1149	0	1	Niagara Falls(0.1 ug/L)
1,3-DCB	1164	0	2	Elgin-St. Thomas (0.1 ug/L)
1,4-DCB	1157	0	6	South Peel (0.2 ug/L)
1,2,3-TCB	1177	5	28	Burlington (20 ng/L)
1,2,4-TCB	1158	5	17	Brantford (24 ng/L)
1,3,5-TCB	1185	5	14	Brantford (17 ng/L)
1,2,3,4-TeCB	1197	1	2	Belleville (19 ng/L)
1,2,3,5-TeCB	1196	1	13	Brantford (13 ng/L)
1,2,4,5-TeCB	1202	1	14	Ottawa (Lemieux Is.) (10 ng/L)
QCB	1191	1	9	Wallaceburg (2 ng/L)
HCB	1147	1	2	Brantford (1 ng/L)
2,3,4-TCP	135	50	0	
2,4,5-TCP	135	50	0	
2,4,6-TCP	135	50	1	Ottawa (Britannia) (50 ng/L-trace)
2,3,4,5-TeCP	135	50	0	
2,3,4,6-TeCP	135	50	0	
PCP	135	50	3	Dresden (10 ng/L-trace)
Benzo(a)pyrene	271	0	2	Hamilton (5 ng/L)

Table 2.2b Residue Levels in Drinking Water: Organics

Chemical	Sample Location	Year(s) Collected	N	Range	Detect. Freq. %	Detect. Limit	Reference	Comments
Lindane	Ontario	1986	1,038	BDL - 11 ng/L	20.8	1.0 ng/L	OMOE, 1987	
1,2 - DCB	Ontario	1986	1,161	BDL - .1 ug/L	0.0	0 ng/L	OMOE, 1987	1,2,3
1,3 - DCB	Ontario	1986	1,164	BDL - .1 ug/L	0.0	0 ng/L	OMOE, 1987	1,2,3
1,4 - DCB	Ontario	1986	1,158	BDL - .2 ug/L	0.0	0 ng/L	OMOE, 1987	1,2,3
1,2,3 - TCB	Ontario	1986	1,177	BDL - 20 ng/L	0.02	5 ng/L	OMOE, 1987	1,3
1,2,4 - TCB	Ontario	1986	1,158	BDL - 24 ng/L	0.01	5 ng/L	OMOE, 1987	1,3
1,3,5 - TCB	Ontario	1986	1,185	BDL - 17 ng/L	0.01	5 ng/L	OMOE, 1987	1,3
1,2,3,4 - TeCB	Ontario	1986	1,197	BDL - 18 ng/L	0.0	1 ng/L	OMOE, 1987	1,3
1,2,3,5 - TeCB	Ontario	1986	1,196	BDL - 13 ng/L	0.01	1 ng/L	OMOE, 1987	1,3
1,2,4,5 - TeCB	Ontario	1986	1,202	BDL - 10 ng/L	0.01	1 ng/L	OMOE, 1987	1,3
QCB	Ontario	1986	1,191	BDL - 2 ng/L	0.0	1 ng/L	OMOE, 1987	1,3
2,3,4 - TCP	Ontario	1986	135	BDL - 50 ng/L	0.0	50 ng/L	OMOE, 1987	1,3
2,4,5 - TCP	Ontario	1986	135		0.0	50 ng/L	OMOE, 1987	1,3
2,4,6 - TCP	Ontario	1986	135		0.7	50 ng/L	OMOE, 1987	1,3
2,3,4,5 - TCP	Ontario	1986	135		0.0	50 ng/L	OMOE, 1987	1,3
2,3,4,6 - TCP	Ontario	1986	135		0.0	50 ng/L	OMOE, 1987	1,3
PCP	Ontario	1986	135	BDL - 10 ng/L	3.0	50 ng/L	OMOE, 1987	1,3

1. Analytical Technique - Gas Chromatography.
2. The MDL for a number of these compounds was reported as zero. However, MDLs must, in practice, always be greater than zero.
3. BDL in the range column refers to "below detection limits".

Table 2.2c Residue Levels in Water: Metals

Chemical	Sample Location	Year(s) Collected	N	Mean	Range	Stand. Mean (µg/L)	Detect. Freq. %	Detect. Limit	Reference	Comments
Lead	Canada	1971-1972	234	30.0 µg/L		30.0	92.3	1 ppb	Neri, 1976	1,2a,3a
	Canada	1971-1972	234	9.7 µg/L		9.7	92.3	1 ppb	Neri, 1976	1,2b,3a
	Niagara-on-Lake	1975	.19	0.002 mg/L		2.0			DOE, 1981	
	Niagara-on-Lake	1980	41	0.001 mg/L		1.0			DOE, 1981	
	Central Canada	1980-1984	1495		1 - 46 µg/L			1 µg/L	Task Force on..,1987	6
	Ontario	1986	540		MDL-0.022 mg/L		23.1	0.003mg/L	OMOE, 1987	4
Zinc	Canada	1971-1972	510	0.2 mg/L		200.0	98.8	3 ppb	Neri, 1976	1,2a,3a
	Canada	1971-1972	510	0.3 mg/L		300.0	98.8	3 ppb	Neri, 1976	1,2b,3a
	Niagara-on-Lake	1975	19	0.004 mg/L		4.0			DOE, 1981	
	Niagara-on-Lake	1980	41	0.005 mg/L		5.0			DOE, 1981	
	Central Canada	1980-1985	1312		1 - 1170 µg/L			1 µg/L	Task Force on.., 1987	6
	Ontario	1986	575		MDL -0.540mg/L		78.8	0.001mg/L	OMOE, 1987	4
Nickel	Canada	1971-1972	233	3.9 µg/L		3.9	90.9	1 ppb	Neri, 1976	1,2a,3a
	Canada	1971-1972	233	5.35 µg/L		5.35	90.9	1 ppb	Neri, 1976	1,2b,3a
	Niagara-on-Lake	1975	19	0.002 mg/L		2.0			DOE, 1981	
	Niagara-on-Lake	1980	41	0.003 mg/L		3.0			DOE, 1981	
	Central Canada	1980-1985	1333		1 - 25 µg/L			1 µg/L	Task Force on.., 1987	6
	St. Catharines	1984	2	2.0 µg/L		2.0	100.0	2 µg/L	OMOE, 1984	
	Toronto	1984	2	2.0 µg/L		2.0	100.0	2 µg/L	OMOE, 1984	
	Ontario	1986	540		MDL-0.24 mg/L		44.3	0.001mg/L	OMOE, 1987	4
Chromium	Canada	1971-1972	233	0.3 µg/L		0.3	16.7	1-7 ppb	Neri, 1976	1,2a,3b
	Canada	1971-1972	233	2.05 µg/L		2.05	16.7	1-7 ppb	Neri, 1976	1,2b,3b
	Niagara-on-Lake	1975	19	0.003 mg/L		3.0			DOE, 1981	
	Niagara-on-Lake	1980	41	0.005 mg/L		5.0			DOE, 1981	
	Central Canada	1980-1985			2 - 44 µg/L			2 µg/L	Task Force on.., 1987	6
	Welland	1984	2	2.0 µg/L		2.0	100.0	2 µg/L	OMOE, 1984	
	St. Catharines	1984	2	2.5 µg/L		2.5	100.0	2 µg/L	OMOE, 1984	
	Niagara Falls		2	2.0 µg/L		2.0	100.0	2 µg/L	OMOE, 1984	
	Fort Erie		2	2.0 µg/L		2.0	100.0	2 µg/L	OMOE, 1984	
	Toronto		2	2.0 µg/L		2.0	100.0	2 µg/L	OMOE, 1984	
	Hamilton		2	2.0 µg/L		2.0	100.0	2 µg/L	OMOE, 1984	
	Oshawa		2	2.0 µg/L		2.0	100.0	2 µg/L	OMOE, 1984	
	Ontario	1986	597		MDL-0.006 mg/L		24.5	0.001mg/L	OMOE, 1987	

Table 2.2c Continued

Chemical	Sample Location	Year(s) Collected	N	Mean	Range	Stand. Mean (µg/L)	Detect. Freq. %	Detect. Limit	Reference	Comments
Mercury	Canada	1971-1972	239	9.6 µg/L		9.6	58.1	1 ppb	Neri, 1976	1,2a,3b
	Canada	1971-1972	239	2.1 µg/L		2.1	58.1	1 ppb	Neri, 1976	1,2b,3b
	Niagara-on-Lake	1979	39	0.00005 mg/L		0.05		0.05 µg/L	DOE, 1981	5
	Niagara-on-Lake	1980	41	0.00005 mg/L		0.05		0.05 µg/L	DOE, 1981	5
	Central Canada	1980-1981	622		0.005 -0.1µg/L			0.05 µg/L	Task Force on.., 1987	5,6
	Ontario	1986	687		MDL-0.38 µg/L		76.9	0.01 µg/L	OMOE, 1987	4
Copper	Canada	1971-1972	510	0.6 mg/L		600.0	94.3	5 ppb	Neri, 1976	1,2a,3a
	Canada	1971-1972	510	0.3 mg/L		300.0	94.3	5 ppb	Neri, 1976	1,2b,3a
	Niagara-on-Lake	1975	19	.004 mg/L		4.0			DOE, 1981	
	Niagara-on-Lake	1980	41	.003 mg/L		3.0			DOE, 1981	
	Central Canada	1981-1983	1333		1 - 68 µg/L			1 µg/L	Task Force on.., 1987	6
	Ontario	1986	600		MDL-0.33 mg/L		97.0	0.001mg/L	OMOE,1987	4
Cadmium	Canada	1971-1972	510	0.65 µg/L		0.65	13.9	1 ppb	Neri, 1976	1,2a,3a
	Canada	1971-1972	510	0.30 µg/L		0.30	13.9	1 ppb	Neri, 1976	1,2b,3a
	Niagara-on-Lake	1975	19	0.001 mg/L		1.0		0.001mg/L	DOE, 1981	5
	Niagara-on-Lake	1980	41	0.001 mg/L		1.0		0.001mg/L	DOE, 1981	5
	Canada		3067		MDL-61 µg/L		0.1	10 µg/L	Task Force on.., 1987	6
	Ontario	1986	473		MDL-10.0 µg/L		24.5	0.3 µg/L	OMOE, 1987	4
Arsenic	Central Canada	1980-1985	428		MDL-2 µg/L		0.2	1.0 µg/L	Task Force on.., 1987	6
	Ontario	1986	595		MDL-0.003 µg/L		1.2	0.001 µg/L	OMOE, 1987	4
Selenium	Central Canada	1980-1981	139		0.1 - 4.0 µg/L			0.1 µg/L	Task Force on.., 1987	6
	Ontario	1986	595		MDL-0.001 mg/L		0.2	0.001mg/L	OMOE, 1987	4

1. Represents total number of Canadian municipalities tested, all levels of water hardness.
2. Total water hardness measured in ppm of calcium carbonate
2a. less than 30 ppm.
2b. greater than 150 ppm.
3. Analytical technique used
3a. Atomic Absorption.
3b. Neutron Absorption.
4. Distribution system, free flow values were selected for tabulation in most cases. Treated values or raw water values were selected if free flow values were unavailable.
5. This median or range value is less than or equal to the detection limit.
6. "Central Canada" refers to Ontario and Quebec.

PATHWAYS OF HUMAN EXPOSURE
TO TOXIC CHEMICALS: AIR

Table 2.3a Residue Levels in Ambient Air: Cadmium, Nickel, and Chromium

Chemical	Sample Location	Year(s) Collected	N	Mean ($\mu g/m^3$)	SD	Range ($\mu g/m^3$)	Detection Limit	Reference	Comments
Cadmium	S. Ontario	1986	2309	0.000-0.001		MAX. 0.023	0.0005 $\mu g/m^3$	OMOE, 1988	2,3a,6,8,9
	W. Ontario	1986	450	0 000-0.004		MAX. 0.074	0.0005 $\mu g/m^3$	OMOE, 1988	2,3a,6,8,9
	Central Ont.	1986	2153	0.000-0.003		MAX. 0.685	0.0005 $\mu g/m^3$	OMOE, 1988	2,3a,6,8,9
	N. Ontario	1986	519	0.000-0.001		MAX. 0.062	0.0005 $\mu g/m^3$	OMOE, 1988	2,3a,6,8,9
	Windsor	1987	2	<0.003	0.023	<0.003-0.003	3.3 ng/m^3	DOE, 1988b	1,3c,5
Nickel	S. Ontario	1986	2360	0.001-0.030		MAX. 0.960	0.005 $\mu g/m^3$	OMOE, 1988	2,3a,6,8,9
	W. Ontario	1986	451	0.002-0.004		MAX. 0.028	0.005 $\mu g/m^3$	OMOE, 1988	2,3a,6,8,9
	Central Ont.	1986	2153	0.001-0.005		MAX. 1.620	0.005 $\mu g/m^3$	OMOE, 1988	2,3a,6,8,9
	N. Ontario	1986	519	0.001-0.183		MAX. 2.290	0.005 $\mu g/m^3$	OMOE, 1988	2,3a,6,8,9
	Windsor	1987	2	0.005	0.003	0.009-0.039	1.1 ng/m^3	DOE, 1988b	1,3c,5
Chromium	S. Ontario	1986	2306	0.003-0.020		MAX. 0.086	0.005 $\mu g/m^3$	OMOE, 1988	2,3a,6,7,8,9
	W. Ontario	1986	451	0.005-0.006		MAX. 0.033	0.005 $\mu g/m^3$	OMOE, 1988	2,3a,6,7,8,9
	Central Ont.	1986	1925	0.003-0.010		MAX. 1.250	0.005 $\mu g/m^3$	OMOE, 1988	2,3a,6,7,8,9
	N. Ontario	1986	519	0.004-0.011		MAX. 0.035	0.005 $\mu g/m^3$	OMOE, 1988	2,3a,6,7,8,9
	Windsor	1987	2	0.015	0.006	0.005-0.029	3.2 ng/m^3	DOE, 1988b	1,3c,5

See notes at end of Table 2.3 c.

Table 2.3b Residue Levels in Ambient Air: Lead

Sample Location	Year(s) Collected	N	Mean (μg/m³)	SD	Range (μg/m³)	Detect. Limit	Reference	Comments
Ontario	1977	14	0.5			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1978	14	0.4			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1979	14	0.3			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1980	14	0.3			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1980	28	0.3		0.04-0.87	0.1 μg/m³	DOE, 1981b	1,3b,3c,4,5
Ontario	1981	14	0.3			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1981	30	0.28		0.04-1.10	0.1 μg/m³	DOE, 1982	1,3b,3c,4,5
Ontario	1982	14	0.2			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1982	33	0.22		0.04-0.66	0.1 μg/m³	DOE, 1983	1,3b,3c,4,5
Ontario	1983	14	0.2			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1983	31	0.22		0.02-0.52	0.1 μg/m³	DOE, 1984	1,3b,3c,4,5
Ontario	1984	14	0.2			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1984	27	0.25		0.01-0.55	0.1 μg/m³	DOE, 1985	1,3b,3c,4,5
Ontario	1985	14	0.2			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1985	27	0.19		0.10-0.39	0.1 μg/m³	DOE, 1986	1,3b,3c,4,5
Ontario	1986	14	0.2			0.01 μg/m³	OMOE, 1988	1,2,3a,8
Ontario	1986	22	0.13		0.02-0.34	0.1 μg/m³	DOE, 1988a	1,3b,3c,4,5
Windsor	1987	2	0.077	0.023	0.041-0.139	0.8 ng/m³	DOE, 1988b	1,3c,6

See notes at end of Table 2.3c.

Table 2.3c Residue Levels in Ambient Air: Copper

Sample Location	Year(s) Collected	N	Mean ($\mu g/m^3$)	SD	Range ($\mu g/m^3$)	Detect. Limit	Reference	Comments
Ontario	1977	18	0.22			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1978	18	0.24			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1979	18	0.23			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1980	18	0.25			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1981	18	0.19			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1982	18	0.17			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1983	18	0.21			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1984	18	0.18			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1985	18	0.17			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Ontario	1986	18	0.15			0.001 $\mu g/m^3$	OMOE, 1988	1,2,3a,8,9
Windsor	1987	2	0.022	0.008	0.009-0.039	1.7 ng/m^3	DOE, 1988b	1,3a,6

1. Total number of stations sampled, may not equal number of samples.
2. Corrections for recovery were not specified.
3. Laboratory Analysis Technique
3a. Flame Atomic Absorption.
3b. Atomic Absorption.
3c. X - ray Fluorescence.
4. This appears to be a detection limit but was termed "Minimum Concentration Limit."
5. Reporting for surrogate and performance recoveries is complete. No corrections appear to be made.
6. Range of Geometric means.
7. The Ministry of Environment uses the term "Reporting Limit" as a rough equivalent to "detection limit" and "Qualifying Limit" as an equivalent to five to ten times the "detection limit." The limit indicated here is the "reporting limit."
8. Only the maximum value was available for the range.
9. The mean column is a range of means. Each separate monitoring station has its own geometric mean.

Table 2.3d Residue Levels in Ambient Air: Organics

Chemical	Sample Location	Year(s) Collected	N	Mean	SD	Range	Detect. Freq. %	Detect. Limit	Reference	Comments
PAHs	Toronto	1984-86	42	47.97 ng/m³	27.26	0.70-162.63 ng/m³		0.06 ng/m³	Dann, 1988	3a
PAHs	Windsor	1987	16	72.81 ng/m³	54.94	ND-193.88 ng/m³	48.4	0.02-0.05 ng/m³	DOE, 1988b	3a
CPs	Windsor	1987	5	1.60 ng/m³	1.13	ND-3.11 ng/m³	40.0	0.02-0.05 ng/m³	DOE, 1988b	3a
PCDD	Windsor	1987	32	2.06 pg/m³	0.41	ND-2.53 pg/m³	28.1	0.04-0.20 pg/m³	DOE, 1988b	3a
PCDF	Windsor	1987	32	0.53 pg/m³	0.53	ND-1.03 pg/m³	34.6	0.04-0.20 pg/m³	DOE, 1988b	
PCB	Great Lakes	1966-81		1.0 ng/m³		0.4-3.0 ng/m3			Eisenrich et al., 1981	1
PCB	Niagara Falls	1987		0.31 ng/m³		0.07-0.68 ng/m3		0.05-0.07 ng/m³	Hoff et al, 1987	2,3a,4a
PCB	Niagara Falls	1987		0.35 ng/m³		0.15-0.66 ng/m³		0.06-0.07 ng/m³	Hoff et al, 1987	2,3a,4b
PCB	Windsor	1987	5	1.11 ng/m³	0.78	ND-2.40 ng/m³	15.3	0.04-0.08 ng/m³	DOE, 1988b	3a
HCB	Great Lakes	1966-1981		0.2 ng/m³		0.1-0.3			Eisenreich et al.,1981	1
HCB	Windsor	1987	5	0.14 ng/m³	0.07	ND-0.24	40.0	0.02 ng/m³	DOE, 1988b	3a
CBs	Windsor	1987	5	2.71 ng/m³	1.75	ND-5.04	40.0	0.02 ng/m³	DOE, 1988b	

1. Summarized existing literature for information on Great Lakes Air Quality in both Canada and United States.
2. Represents 2,4',5-Trichlorobiphenyl.
3. Analytical Techniques
3a. Gas Chromatography.
4. Niagara Falls, Ontario, had two sampling locations
4a. Above Falls.
4b. In Niagara Gorge.

HUMAN TISSUE DATA: ADIPOSE TISSUE

Table 3.1a Residue Levels in Human Adipose Tissue (Lipid Weight): Chlordane and Related Species

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
S.W. Ontario	chlordane	1976-77	125	0.04 mg/kg	0.06		40	76	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	chlordane	1978-79	111	0.07 mg/kg	0.06		70	92.7	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	chlordane	1980-81	125	0.02 mg/kg	0.03		20	86.8	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	chlordane	1983-84	209	0.012 mg/kg	0.021		12	24.4	5 µg/kg	Frank et al., 1988	6
Cornwall	oxychlordane	1984	21	32 ng/g	13	11-170	32	100	1.2 ng/g	Williams et al., 1988	1, 7
London	oxychlordane	1984	37	56 ng/g	26	19-108	56	100	1.2 ng/g	Williams et al., 1988	1, 7
St. Catharines	oxychlordane	1984	17	70 ng/g	53	31-237	70	100	1.2 ng/g	Williams et al., 1988	1, 7
Toronto	oxychlordane	1984	7	45 ng/g	19	18-69	45	100	1.2 ng/g	Williams et al., 1988	1, 7
Welland	oxychlordane	1984	23	43 ng/g	28	14-105	43	100	1.2 ng/g	Williams et al., 1988	1, 7
Windsor	oxychlordane	1984	36	61 ng/g	35	7.7-143	61	100	1.2 ng/g	Williams et al., 1988	1, 7
Ontario	oxychlordane	1984	141	53 ng/g	33	7.7-237	53	100	1.2 ng/g	Williams et al., 1988	1, 7
Alberta	chlordane	1967-68	51	ND			ND	0		Kadis et al., 1970	4, 7, 8

See notes at end of Table 3.1u.

Table 3.1b Residue Levels in Human Adipose Tissue (Wet Weight): Chlordane and Related Species

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	oxychlordane	1972	57	0.070 µg/g	0.063		70			Mes et al., 1977	7, 8
Ontario	oxychlordane	1976	6	0.054 µg/g	0.017		54			Mes et al., 1982	7, 8
Kingston	oxychlordane	1979-81	91	42 ng/g	18	10-120	42	100	10 ng/g	Williams et al., 1984	1, 7
Kingston	α-chlordane	1979-81	91	ND			ND	0	10 ng/g	LeBel and Williams, 1986	1, 7, 18
Ottawa	oxychlordane	1980-81	84	39 ng/g	16	10-110	39	100	10 ng/g	Williams et al., 1984	1, 7
Ottawa	α-chlordane	1980-81	84	ND			ND	0	10 ng/g	LeBel and Williams, 1986	1, 7, 18
Canada	oxychlordane	1972	168	0.055 µg/g	0.047	0.003-0.336	55	97		Mes et al., 1977	7, 8
Canada	oxychlordane	1976	99	0.055 µg/g	0.026	0.005-0.186	55	100		Mes et al., 1982	7, 8

See notes at end of Table 3.1u.

Table 3.1c Residue Levels in Human Adipose Tissue (Lipid Weight): Dieldrin

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
S. Ontario	1969	3	0.09 ppm		0.06-0.11	90			Boldrinet et al., 1977	6
Ontario	1969	5	0.13 ppm		0.09-0.31	130			Boldrinet et al., 1977	3, 6
S. Ontario	1970	29	0.20 ppm		0.03-0.56	200			Boldrinet et al., 1977	6
S. Ontario	1971	97	0.16 ppm		ND-0.88	160			Boldrinet et al., 1977	6
S. Ontario	1972	126	0.10 ppm		ND-0.43	100			Boldrinet et al., 1977	6
Ontario	1972	59	0.11 ppm		0.01-0.44	110			Boldrinet et al., 1977	3, 6
S. Ontario	1973	38	0.17 ppm		0.03-1.30	170			Boldrinet et al., 1977	6
Ontario	1973	63	0.07 ppm		trace-0.26	70			Boldrinet et al., 1977	3, 6
S. Ontario	1974	28	0.07 ppm		ND-0.16	70			Boldrinet et al., 1977	6
S.W. Ontario	1976-77	125	0.04 mg/kg	0.05		40	84.8	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1978-79	111	0.01 mg/kg	0.09		10	97.2	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1980-81	125	0.11 mg/kg	0.13		110	100	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1983-84	209	0.029 mg/kg	0.042		29	94.1	5 µg/kg	Frank et al., 1988	6
Cornwall	1984	21	19 ng/g	12	ND-51	19	96	0.9 ng/g	Williams et al., 1988	1, 7
London	1984	37	63 ng/g	42	6.5-151	63	100	0.9 ng/g	Williams et al., 1988	1, 7
St. Catharines	1984	17	54 ng/g	50	3.8-201	54	100	0.9 ng/g	Williams et al., 1988	1, 7
Toronto	1984	7	32 ng/g	23	15-79	32	100	0.9 ng/g	Williams et al., 1988	1, 7
Welland	1984	23	33 ng/g	23	7.3-84	33	100	0.9 ng/g	Williams et al., 1988	1, 7
Windsor	1984	36	54 ng/g	47	7.2-235	54	100	0.9 ng/g	Williams et al., 1988	1, 7
Ontario	1984	141	47 ng/g	41	ND-235	47	99	0.9 ng/g	Williams et al., 1988	1, 7
Alberta	1967-68	51	0.12 ppm	0.03	<0.002-0.83	120			Kadis et al., 1970	4, 7, 8

See notes at end of Table 3.1u.

Table 3.1d Residue Levels in Human Adipose Tissue (Wet Weight): Dieldrin and Aldrin

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Toronto	Dieldrin	1966	47	0.22 ppm	0.12	0.07–0.53	220	74	0.5 ug	Brown, 1967	2, 7
Toronto	Aldrin	1966	47	0.03 ppm	0.02	0.01–0.14	30	85	0.5 ug	Brown, 1967	2, 7
Ottawa	Dieldrin	1969	40	0.083 mg/kg	0.050	0.02–0.24	83			Ritcey et al., 1973	6, 8
Toronto	Dieldrin	1969	50	0.162 mg/kg	0.093	0.02–0.46	162			Ritcey et al., 1973	6, 8
Ontario	Dieldrin	1972	57	0.085 µg/g	0.062		85	100		Mes et al., 1977	7, 8
Ontario	Dieldrin	1976	6	0.049 µg/g	0.026		49			Mes et al., 1982	7, 8
Kingston	Dieldrin	1979–81	91	36 ng/g	28	ND–120	36	88	10 ng/g	Williams et al, 1984	1, 7
Ottawa	Dieldrin	1980–81	84	43 ng/g	28	ND–130	43	95	10 ng/g	Williams et al, 1984	1, 7
Canada	Dieldrin	1969	221	0.122 mg/kg	0.075	0.02–0.46	122			Ritcey et al., 1973	6, 8
Canada	Dieldrin	1972	168	0.069 µg/g	0.055	0.001–0.353	69	100		Mes et al., 1982	7, 8
Canada	Dieldrin	1976	99	0.049 µg/g	0.030	0.003–0.211	49	100		Mes et al., 1982	7, 8

See notes at end of Table 3.1u.

Table 3.1e Residue Levels in Human Adipose Tissue (Lipid Weight): DDT and Related Species

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (µg/g)	Det. Freq. %	Detect. Limit	Reference	Comments
S. Ontario	Total DDT	1969	3	7.10 ppm		2.57-11.9	7.10			Holdrinet et al., 1977	6, 14
Ontario	Total DDT	1969	5	5.16 ppm		1.40-12.3	5.16			Holdrinet et al., 1977	3, 6, 14
S. Ontario	Total DDT	1970	29	8.06 ppm		1.32-29.6	8.06			Holdrinet et al., 1977	6, 14
S. Ontario	Total DDT	1971	97	6.69 ppm		0.50-20.5	6.69			Holdrinet et al., 1977	6, 14
S. Ontario	Total DDT	1972	126	5.56 ppm		0.81-18.8	5.56			Holdrinet et al., 1977	6, 14
Ontario	Total DDT	1972	59	4.36 ppm		0.49-13.3	4.36			Holdrinet et al., 1977	3, 6, 14
S. Ontario	Total DDT	1973	38	3.94 ppm		0.46-10.1	3.94			Holdrinet et al., 1977	6, 14
Ontario	Total DDT	1973	63	3.80 ppm		0.68-13.4	3.80			Holdrinet et al., 1977	3, 6, 14
S. Ontario	Total DDT	1974	28	3.12 ppm		0.67-7.59	3.12			Holdrinet et al., 1977	6, 14
S.W. Ontario	Total DDT	1976-77	125	5.13 mg/kg	5.5		5.13	100	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	Total DDT	1978-79	111	6.30 mg/kg	5.6		6.30	100	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	Total DDT	1980-81	125	4.60 mg/kg	4.7		4.60	100	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	Total DDT	1983-84	209	2.63 mg/kg	4.8		2.63	100	5 µg/kg	Frank et al., 1988	6
Cornwall	p,p'-DDT	1984	21	70 ng/g	36	13-234	0.070	100	1.7 ng/g	Williams et al., 1988	1, 7
Cornwall	p,p'-DDE	1984	21	2163 ng/g	2031	466-8049	2.163	100	1.2 ng/g	Williams et al., 1988	1, 7
Cornwall	p,p'-DDD/o,p'-DDT	1984	21	4.3 ng/g	2.3	ND-11	0.004	62	4.0 ng/g	Williams et al., 1988	1, 7
London	p,p'-DDT	1984	37	61 ng/g	55	6.6-218	0.061	100	1.7 ng/g	Williams et al., 1988	1, 7
London	p,p'-DDE	1984	37	3101 ng/g	1970	364-7217	3.101	100	1.2 ng/g	Williams et al., 1988	1, 7
London	p,p'-DDD/o,p'-DDT	1984	37	5.9 ng/g	6.2	ND-36	0.006	97	4.0 ng/g	Williams et al., 1988	1, 7
St. Catharines	p,p'-DDT	1984	17	80 ng/g	99	7.6-369	0.080	100	1.7 ng/g	Williams et al., 1988	1, 7
St. Catharines	p,p'-DDE	1984	17	4355 ng/g	2784	453-10 326	4.355	100	1.2 ng/g	Williams et al., 1988	1, 7
St. Catharines	p,p'-DDD/o,p'-DDT	1984	17	4.1 ng/g	4.8	ND-20	0.004	29	4.0 ng/g	Williams et al., 1988	1, 7
Toronto	p,p'-DDT	1984	7	67 ng/g	46	27-148	0.067	100	1.7 ng/g	Williams et al., 1988	1, 7
Toronto	p,p'-DDE	1984	7	1972 ng/g	1404	809-4412	1.972	100	1.2 ng/g	Williams et al., 1988	1, 7
Toronto	p,p'-DDD/o,p'-DDT	1984	7	5.5 ng/g	2.5	ND-9.7	0.006	86	4.0 ng/g	Williams et al., 1988	1, 7
Welland	p,p'-DDT	1984	23	108 ng/g	97	17-332	0.108	100	1.7 ng/g	Williams et al., 1988	1, 7
Welland	p,p'-DDE	1984	23	3411 ng/g	2633	245-11 161	3.411	100	1.2 ng/g	Williams et al., 1988	1, 7
Welland	p,p'-DDD/o,p'-DDT	1984	23	3.8 ng/g	2.3	ND-9	0.004	52	4.0 ng/g	Williams et al., 1988	1, 7
Windsor	p,p'-DDT	1984	36	101 ng/g	91	8.5-343	0.101	100	1.7 ng/g	Williams et al., 1988	1, 7
Windsor	p,p'-DDE	1984	36	3758 ng/g	3239	130-12 167	3.758	100	1.2 ng/g	Williams et al., 1988	1, 7
Windsor	p,p'-DDD/o,p'-DDT	1984	36	7.6 ng/g	6.6	ND-30	0.008	78	4.0 ng/g	Williams et al., 1988	1, 7
Ontario	p,p'-DDT	1984	141	84 ng/g	80	7-369	0.084	100	1.7 ng/g	Williams et al., 1988	1, 7
Ontario	p,p'-DDE	1984	141	3237 ng/g	2602	130-12 167	3.237	100	1.2 ng/g	Williams et al., 1988	1, 7
Ontario	p,p'-DDD/o,p'-DDT	1984	141	5.5 ng/g	5.2	ND-36	0.0055	71	4.0 ng/g	Williams et al., 1988	1, 7
Alberta	p,p'-DDT	1967-68	51	1.56 ppm	0.19	0.19-7.28	1.56			Kadis et al., 1970	4, 7, 8
Alberta	p,p'-DDE	1967-68	51	4.16 ppm	0.46	0.04-11.51	4.16			Kadis et al., 1970	4, 7, 8
Alberta	p,p'-DDD	1967-68	51	0.15 ppm	0.02	<0.002-0.93	0.15			Kadis et al., 1970	4, 7, 8

See notes at end of Table 3.1u.

Table 3.1f Residue Levels in Human Adipose Tissue (Wet Weight): DDT and Related Species

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (µg/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Toronto	p,p'-DDT	1966	47	1.09 ppm	0.49	0.28-2.65	1.09	100	0.1 ug	Brown, 1967	2, 7
Toronto	p,p'-DDE	1966	47	2.66 ppm	1.32	0.6-6.8	2.66	100	0.5 ug	Brown, 1967	2, 7
Toronto	DDD	1966	47	0.3 ppm	0.19	0.01-0.90	0.3	57		Brown, 1967	2, 7
Ottawa	p,p'-DDT	1969	40	0.902 mg/kg	0.647	0.09-2.93	0.902			Ritcey et al., 1973	6, 8
Ottawa	p,p'-DDE	1969	40	3.228 mg/kg	2.680	0.09-11.00	3.228			Ritcey et al., 1973	6, 8
Ottawa	o,p'-DDT	1969	40	0.039 mg/kg	0.040	<0.01-0.21	0.039			Ritcey et al., 1973	6, 8
Ottawa	p,p'-TDE	1969	40	0.046 mg/kg	0.026	<0.01-0.12	0.046			Ritcey et al., 1973	6, 8
Ottawa	Total DDT	1969	40	4.197 mg/kg	3.175	0.18-12.32	4.197			Ritcey et al., 1973	6, 8
Toronto	p,p'-DDT	1969	50	1.246 mg/kg	0.923	0.13-4.00	1.246			Ritcey et al., 1973	6, 8
Toronto	p,p'-DDE	1969	50	3.977 mg/kg	2.895	0.11-16.86	3.977			Ritcey et al., 1973	6, 8
Toronto	o,p'-DDT	1969	50	0.047 mg/kg	0.049	<0.01-0.30	0.047			Ritcey et al., 1973	6, 8
Toronto	p,p'-TDE	1969	50	0.067 mg/kg	0.060	<0.01-0.23	0.067			Ritcey et al., 1973	6, 8
Toronto	Total DDT	1969	50	5.330 mg/kg	3.583	0.32-18.71	5.330			Ritcey et al., 1973	6, 8
Ontario	p,p'-DDT	1972	57	0.372 µg/g	0.256		0.372	100		Mes et al., 1977	7, 8
Ontario	p,p'-DDE	1972	57	2.008 µg/g	2.027		2.008	100		Mes et al., 1977	7, 8
Ontario	o,p'-DDT	1972	57	0.032 µg/g	0.035		0.032			Mes et al., 1977	7, 8
Ontario	p,p'-TDE	1972	57	0.010 µg/g	0.056		0.010			Mes et al., 1977	7, 8
Ontario	p,p'-DDT	1976	6	0.225 µg/g	0.146		0.225			Mes et al., 1982	7, 8
Ontario	p,p'-DDE	1976	6	1.53 µg/g	1.215		1.53			Mes et al., 1982	7, 8
Ontario	o,p'-DDT	1976	6	0.034 µg/g	0.041		0.034			Mes et al., 1982	7, 8
Kingston	p,p'-DDT	1979-81	91	159 ng/g	156	ND-740	0.159	99	10 ng/g	Williams et al., 1984	1, 7
Kingston	p,p'-DDE	1979-81	91	3256 ng/g	2856	10-17 100	3.256	100	10 ng/g	Williams et al., 1984	1, 7
Kingston	p,p'-DDD	1979-81	91	14 ng/g	11	ND-80	0.014	67	10 ng/g	Williams et al., 1984	1, 7, 16
Ottawa	p,p'-DDT	1980-81	84	128 ng/g	107	ND-740	0.128	98	10 ng/g	Williams et al., 1984	1, 7
Ottawa	p,p'-DDE	1980-81	84	2557 ng/g	2013	80-10 200	2.557	100	10 ng/g	Williams et al., 1984	1, 7
Ottawa	p,p'-DDD	1980-81	84	9 ng/g	9	ND-60	0.009	37	10 ng/g	Williams et al., 1984	1, 7, 16
Canada	p,p'-DDT	1969	221	1.017 mg/kg	0.708	0.08-4.20	1.017			Ritcey et al., 1973	6, 8
Canada	p,p'-DDE	1969	221	3.430 mg/kg	2.222	0.09-16.86	3.430			Ritcey et al., 1973	6, 8
Canada	o,p'-DDT	1969	221	0.049 mg/kg	0.042	<0.01-0.30	0.049			Ritcey et al., 1973	6, 8
Canada	p,p'-TDE	1969	221	0.064 mg/kg	0.064	<0.01-0.60	0.064			Ritcey et al., 1973	6, 8
Canada	Total DDT	1969	221	4.543 mg/kg	2.732	0.18-18.71	4.543			Ritcey et al., 1973	6, 8
Canada	p,p-DDT	1972	168	0.439 µg/g	0.332	0.018-2.057	0.439	100		Mes et al., 1977	7, 8
Canada	p,p'-DDE	1972	168	2.095 µg/g	1.697	0.054-15.534	2.095	100		Mes et al., 1977	7, 8
Canada	o,p'-DDT	1972	168	0.031 µg/g	0.036	0.001-0.229	0.031	63		Mes et al., 1977	7, 8
Canada	p,p'-TDE	1972	168	0.006 µg/g	0.036	0.002-0.402	0.006	26		Mes et al., 1977	7, 8
Canada	p,p'-DDT	1976	99	0.311 µg/g	0.493	0.016-3.998	0.311	100		Mes et al., 1982	7, 8
Canada	p,p'-DDE	1976	99	1.721 µg/g	1.390	0.034-7.819	1.721	100		Mes et al., 1982	7, 8
Canada	o,p'-DDT	1976	99	0.032 µg/g	0.058	0.005-0.578	0.032	96		Mes et al., 1982	7, 8

See notes at end of Table 3.1u.

Table 3.1g Residue Levels in Human Adipose Tissue (Lipid Weight): Hexachlorobenzene

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Detect. Freq. %	Detect. Limit	Reference	Comments
Ontario	1971-72	33	0.09 ppm		ND-0.50	90			Holdrinet et al., 1977	6, 8
Ontario	1973-74	76	0.12 ppm		ND-0.43	120			Holdrinet et al., 1977	6, 8
S.W. Ontario	1976-77	125	0.03 mg/kg	0.02		30	93.1	5 µg/kg	Frank et al., 1988	6, 8
S.W. Ontario	1978-79	111	0.03 mg/kg	0.03		30	93.1	5 µg/kg	Frank et al., 1988	6, 8
S.W. Ontario	1980-81	125	0.02 mg/kg	0.02		20	92.8	5 µg/kg	Frank et al., 1988	6, 8
S.W. Ontario	1983-84	209	0.01 mg/kg	0.01		10	91.9	5 µg/kg	Frank et al., 1988	6, 8
Cornwall	1984	21	71 ng/g	36	26-178	71	100	1.4 ng/g	Williams et al., 1988	1, 7
London	1984	37	89 ng/g	51	25-244	89	100	1.4 ng/g	Williams et al., 1988	1, 7
St. Catharines	1984	17	114 ng/g	85	39-373	114	100	1.4 ng/g	Williams et al., 1988	1, 7
Toronto	1984	7	58 ng/g	30	28-102	58	100	1.4 ng/g	Williams et al., 1988	1, 7
Welland	1984	23	84 ng/g	64	18-258	84	100	1.4 ng/g	Williams et al., 1988	1, 7
Windsor	1984	36	80 ng/g	50	19-238	80	100	1.4 ng/g	Williams et al., 1988	1, 7
Ontario	1984	141	84 ng/g	56	18-373	84	100	1.4 ng/g	Williams et al., 1988	1, 7

See notes at end of Table 3.1u.

Table 3.1h Residue Levels in Human Adipose Tissue (Wet Weight): Hexachlorobenzene

Sample Location	Year(s) Collected	N	Repeated Mean	SD	Range	Stand. Mean (ng/g)	Detect. Freq. %	Detect. Limit	Reference	Comments
Ontario	1972	57	0.060 µg/g	0.075		60	100		Mes et al., 1977	7, 8
Ontario	1976	6	0.082 µg/g	0.048		82	100		Mes et al., 1982	7, 8
Kingston	1979-81	91	106 ng/g	70	10-458	106	100	10 ng/g	Williams et al., 1984	1, 7
Ottawa	1980-81	84	78 ng/g	52	17-315	78	100	10 ng/g	Williams et al., 1984	1, 7
Canada	1972	168	0.062 µg/g	0.155	0.001-0.520	62	100		Mes et al., 1977	7, 8
Canada	1976	99	0.095 µg/g	0.103	0.010-0.667	95	100		Mes et al., 1982	7, 8

See notes at end of Table 3.1u.

Table 3.1l Residue Levels in Human Adipose Tissue (Lipid Weight): HCH Isomers

Sample Location	Isomer	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
S.W. Ontario	α- and β-HCH	1976-77	125	ND			ND	0	5 μg/kg	Frank et al., 1988	6
S.W. Ontario	γ-HCH	1976-77	125	ND			ND	0	5 μg/kg	Frank et al., 1988	6
S.W. Ontario	α- and β-HCH	1976-84	13	ND			ND	0	5 μg/kg	Frank et al., 1988	6, 17
S.W. Ontario	γ-HCH	1976-84	13	ND			ND	0	5 μg/kg	Frank et al., 1988	6, 17
S.W. Ontario	α- and β-HCH	1978-79	111	ND			ND	0	5 μg/kg	Frank et al., 1988	6
S.W. Ontario	γ-HCH	1978-79	111	ND			ND	0	5 μg/kg	Frank et al., 1988	6
S.W. Ontario	α- and β-HCH	1980-81	125	0.02 mg/kg	0.02		20	14.4	5 μg/kg	Frank et al., 1988	6
S.W. Ontario	γ-HCH	1980-81	125	ND			ND	0	5 μg/kg	Frank et al., 1988	6
S.W. Ontario	α- and β-HCH	1983-84	209	0.006 mg/kg	0.008		6	20.1	5 μg/kg	Frank et al., 1988	6
S.W. Ontario	γ-HCH	1983-84	209	ND			ND	0	5 μg/kg	Frank et al., 1988	6
Cornwall	α-HCH	1984	21	NC			NC	83	1.2 ng/g	Williams et al., 1988	1, 5, 7
Cornwall	β-HCH	1984	21	51 ng/g	40	16-214	51	100	3.0 ng/g	Williams et al., 1988	1, 7
Cornwall	γ-HCH	1984	21	NC			NC	8	1.4 ng/g	Williams et al., 1988	1, 7
London	α-HCH	1984	37	NC			NC	97	1.2 ng/g	Williams et al., 1988	1, 5, 7
London	β-HCH	1984	37	112 ng/g	93	19-430	112	100	3.0 ng/g	Williams et al., 1988	1, 7
London	γ-HCH	1984	37	NC			NC	19	1.4 ng/g	Williams et al., 1988	1, 7
St. Catharines	α-HCH	1984	17	NC			NC	94	1.2 ng/g	Williams et al., 1988	1, 5, 7
St. Catharines	β-HCH	1984	17	107 ng/g	91	27-366	107	100	3.0 ng/g	Williams et al., 1988	1, 7
St. Catharines	γ-HCH	1984	17	NC			NC	6	1.4 ng/g	Williams et al., 1988	1, 7
Toronto	α-HCH	1984	7	NC			NC	86	1.2 ng/g	Williams et al., 1988	1, 5, 7
Toronto	β-HCH	1984	7	69 ng/g	48	29-148	69	100	3.0 ng/g	Williams et al., 1988	1, 7
Toronto	γ-HCH	1984	7	ND			ND	0	1.4 ng/g	Williams et al., 1988	1, 7
Welland	α-HCH	1984	23	NC			NC	83	1.2 ng/g	Williams et al., 1988	1, 5, 7
Welland	β-HCH	1984	23	76 ng/g	108	16-530	76	100	3.0 ng/g	Williams et al., 1988	1, 7
Welland	γ-HCH	1984	23	NC			NC	17	1.4 ng/g	Williams et al., 1988	1, 7
Windsor	α-HCH	1984	36	NC			NC	67	1.2 ng/g	Williams et al., 1988	1, 5, 7
Windsor	β-HCH	1984	36	74 ng/g	61	14-270	74	100	3.0 ng/g	Williams et al., 1988	1, 7
Windsor	γ-HCH	1984	36	NC			NC	3	1.4 ng/g	Williams et al., 1988	1, 7
Ontario	β-HCH	1984	141	84 ng/g	82	14-530	84	100	3.0 ng/g	Williams et al., 1988	1
Alberta	α-HCH	1967-68	35	1.07 ppm		<0.001-3.76	1.070			Kadis et al., 1970	4, 7, 8

See notes at end of Table 3.1u.

Table 3.1j Residue Levels in Human Adipose Tissue (Wet Weight): HCH Isomers

Sample Location	Isomer	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Toronto	γ-HCH	1966	47	0.07 ppm	0.04	0.01–0.18	70	89	0.5 ug	Brown, 1967	2, 7
Ottawa	γ-HCH	1969	40	0.011 mg/kg	0.007	<0.01–0.03	11			Ritcey et al., 1973	6, 8
Toronto	γ-HCH	1969	50	0.020 mg/kg	0.019	<0.01–0.09	20			Ritcey et al., 1973	6, 8
Ontario	α-HCH	1972	57	0.004 µg/g	0.005		4			Mes et al., 1977	7, 8
Ontario	β-HCH	1972	57	0.075 µg/g	0.227		75			Mes et al., 1977	7, 8
Ontario	γ-HCH	1972	57	0.009 µg/g	0.019		9			Mes et al., 1977	7, 8
Ontario	α-HCH	1976	6	0.004 µg/g	0.008		4			Mes et al., 1982	7, 8
Ontario	β-HCH	1976	6	0.179 µg/g	0.318		179			Mes et al., 1982	7, 8
Ontario	γ-HCH	1976	6	0.001 µg/g	0.000		1			Mes et al., 1982	7, 8
Kingston	α-HCH	1979–81	91	NC			NC	4	10 ng/g	Williams et al., 1984	1, 5, 7, 16
Kingston	β-HCH	1979–81	91	136 ng/g	476	ND–3430	136	99	10 ng/g	Williams et al., 1984	1, 7
Kingston	γ-HCH	1979–81	91	ND			ND	0	10 ng/g	Williams et al, 1984	1, 7
Ottawa	α-HCH	1980–81	84	NC			NC	1	10 ng/g	Williams et al., 1984	1, 5, 7, 16
Ottawa	β-HCH	1980–81	84	65 ng/g	85	10–680	65	100	10 ng/g	Williams et al., 1984	1, 7
Ottawa	γ-HCH	1980–81	84	ND			ND	0	10 ng/g	Williams et al., 1984	1, 7
Canada	γ-HCH	1969	221	0.015 mg/kg	0.017	<0.01–0.17	15			Ritcey et al., 1973	6, 8
Canada	α-HCH	1972	168	0.004 µg/g	0.005	0.001–0.036	4	88		Mes et al., 1977	7, 8
Canada	β-HCH	1972	168	0.054 µg/g	0.144	0.001–1.790	54	88		Mes et al., 1977	7, 8
Canada	γ-HCH	1972	168	0.007 µg/g	0.014	0.001–0.136	7	78		Mes et al., 1977	7, 8
Canada	α-HCH	1976	99	0.004 µg/g	0.000	0.001–0.043	4	97		Mes et al., 1982	7, 8
Canada	β-HCH	1976	99	0.151 µg/g	0.459	0.016–4.413	151	100		Mes et al., 1982	7, 8
Canada	γ-HCH	1976	99	0.003 µg/g	0.000	0.001–0.030	3	90		Mes et al., 1982	7, 8

See notes at end of Table 3.1u

Table 3.1k Residue Levels in Human Adipose Tissue (Lipid Weight): Heptachlor Epoxide

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
S.W. Ontario	1976-77	125	0.05 mg/kg	0.04		50	89.6	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1978-79	111	0.06 mg/kg	0.04		60	93.6	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1980-81	125	0.08 mg/kg	0.06		80	100	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1983-84	209	0.083 mg/kg	0.06		83	96.2	5 µg/kg	Frank et al., 1988	6
Cornwall	1984	21	16 ng/g	10	3.3-39	16	100	1.1 ng/g	Williams et al., 1988	1, 7
London	1984	37	44 ng/g	28	6.9-109	44	100	1.1 ng/g	Williams et al., 1988	1, 7
St. Catharines	1984	17	42 ng/g	38	4.9-150	42	100	1.1 ng/g	Williams et al., 1988	1, 7
Toronto	1984	7	24 ng/g	11	12-41	24	100	1.1 ng/g	Williams et al., 1988	1, 7
Welland	1984	23	24 ng/g	18	2-84	24	100	1.1 ng/g	Williams et al., 1988	1, 7
Windsor	1984	36	35 ng/g	27	6.5-103	35	100	1.1 ng/g	Williams et al., 1988	1, 7
Ontario	1984	141	33 ng/g	27	2-150	33	100	1.1 ng/g	Williams et al., 1988	1, 7
Alberta	1967-68	51	0.14 ppm	0.05	<0.001-1.50	140			Kadis et al., 1970	4, 7, 8

See notes at end of Table 3.1u.

Table 3.1l Residue Levels in Human Adipose Tissue (Wet Weight): Heptachlor Epoxide

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Toronto	1966	47	0.14 ppm	0.09	0.01-0.40	140	47	0.5 ug	Brown, 1967	2, 7
Ottawa	1969	40	0.026 mg/kg	0.022	<0.01-0.12	26			Ritcey et al., 1973	6, 8
Toronto	1969	50	0.035 mg/kg	0.027	<0.01-0.13	35			Ritcey et al., 1973	6, 8
Ontario	1972	57	0.046 µg/g	0.065		46	100		Mes et al., 1977	7, 8
Ontario	1976	6	0.052 µg/g	0.069		52			Mes et al., 1982	7, 8
Kingston	1979-81	91	35 ng/g	20	10-110	35	86	10 ng/g	Williams et al., 1984	1, 7, 16
Ottawa	1980-81	84	37 ng/g	21	10-130	37	95	10 ng/g	Williams et al., 1984	1, 7, 16
Canada	1969	221	0.040 mg/kg	0.036	<0.01-0.20	40			Ritcey et al., 1973	6, 8
Canada	1972	168	0.043 µg/g	0.043	0.003-0.477	43	100		Mes et al., 1977	7, 8
Canada	1976	99	0.037 µg/g	0.045	0.004-0.404	37	100		Mes et al., 1982	7, 8

See notes at end of Table 3.1u.

Table 3.1m Residue Levels in Human Adipose Tissue (Lipid Weight): Mirex

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
S.W. Ontario	1976-77	125	<0.01 mg/kg			<10	32.8	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1978-79	111	<0.01 mg/kg			<10	32.8	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1980-81	125	0.04 mg/kg	0.09		40	64.8	5 µg/kg	Frank et al., 1988	6
S.W. Ontario	1983-84	209	0.06 mg/kg	0.07		60	6.2	5 µg/kg	Frank et al., 1988	6
Cornwall	1984	21	11 ng/g	14	2.7-55	11	100	1.8 ng/g	Williams et al., 1988	1, 7, 15
London	1984	37	7.2 ng/g	7.6	ND-43	7.2	95	1.8 ng/g	Williams et al., 1988	1, 7
St. Catharines	1984	17	20 ng/g	18	ND-51	20	94	1.8 ng/g	Williams et al., 1988	1, 7
Toronto	1984	7	19 ng/g	35	3.5-98	19	100	1.8 ng/g	Williams et al., 1988	1, 7
Welland	1984	23	8.8 ng/g	7.4	ND-24	8.8	70	1.8 ng/g	Williams et al., 1988	1, 7
Windsor	1984	36	9.5 ng/g	6.3	ND-31	9.5	94	1.8 ng/g	Williams et al., 1988	1, 7
Ontario	1984	141	11 ng/g	13	ND-98	11	90	1.8 ng/g	Williams et al., 1988	1, 7

See notes at end of Table 3.1u.

Table 3.1n Residue Levels in Human Adipose Tissue (Wet Weight): Mirex and Photomirex

Sample Location	Specie	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Kingston	Mirex	1979-80	91	27 ng/g	38	ND-190	27	72	10 ng/g	Williams et al., 1984	1, 7
Kingston	Photomirex	1979-81	91	9 ng/g	11	ND-60	9	20	10 ng/g	Williams et al., 1984	1, 7
Ottawa	Mirex	1980-81	84	11 ng/g	16	ND-120	11	38	10 ng/g	Williams et al., 1984	1, 7
Ottawa	Photomirex	1980-81	84	6 ng/g	4	ND-30	6	2	10 ng/g	Williams et al., 1984	1, 7
Quebec/NS/PEI	Mirex	1976	16	6 ppb		2-19	6			Mes et al., 1982	

See notes at end of Table 3.1u.

Table 3.1p Residue Levels in Human Adipose Tissue (Lipid Weight): Dioxins

Sample Location	Congener	Year Collected	N	Reported Mean	Reference
Canada	2,3,7,8-TCDD	1976	46	7.1 pg/g	Ryan, 1986
Canada	1,2,3,7,8-PCDD	1976	46	11 pg/g	Ryan, 1986
Canada	1,2,3,6,7,8-HxCDD	1976	46	97 pg/g	Ryan, 1986
Canada	1,2,3,4,6,7,8-HpCDD	1976	46	151 pg/g	Ryan, 1986
Canada	1,2,3,4,6,7,8,9-OCDD	1976	46	951 pg/g	Ryan, 1986

Table 3.1q Residue Levels in Human Adipose Tissue (Wet Weight): Dioxins

Sample Location	Congener	Year(s) Collected	N	Reported Mean	SD	Range	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	2,3,7,8-TCDD	1976	6	6.1 ppt			83	2-4 ppt	Ryan et al., 1985a	2
Ontario	1,2,3,7,8-PeCDD	1976	6	6.1 ppt			100	2-4 ppt	Ryan et al., 1985a	2
Ontario	1,2,3,6,7,8-HxCDD	1976	6	40.3 ppt			100	2-4 ppt	Ryan et al., 1985a	2
Ontario	1,2,3,4,6,7,8-HpCDD	1976	6	116 ppt			100	2-4 ppt	Ryan et al., 1985a	2
Ontario	1,2,3,4,6,7,8,9-OCDD	1976	6	528 ppt			100	10 ppt	Ryan et al., 1985a	2
E. Ontario	2,3,7,8-TCDD	1980	10	10.0 ppt	4.9	3.0-17.8	100	2-4 ppt	Ryan et al., 1985a	2
E. Ontario	1,2,3,7,8-PCDD	1980	10	13.2 ppt	4.0	10.5-21.4	100	2-4 ppt	Ryan et al., 1985a	2
E. Ontario	1,2,3,6,7,8-HxCDD	1980	10	90.5 ppt	38.9	50-177	100	2-4 ppt	Ryan et al., 1985a	2
E. Ontario	1,2,3,4,6,7,8-HpCDD	1980	10	116 ppt	41.8	53-208	100	2-4 ppt	Ryan et al., 1985a	2
E. Ontario	1,2,3,4,6,7,8,9-OCDD	1980	10	611 ppt	226	317-985	100	10 ppt	Ryan et al., 1985a	2
Canada	2,3,7,8-TCDD	1976	46	6.2 ppt	2.6	ND-12.7	46	2-4 ppt	Ryan et al., 1985a	2
Canada	1,2,3,7,8-PCDD	1976	46	10.4 ppt	5.8	1.5-34.5	100	2-4 ppt	Ryan et al., 1985a	2
Canada	1,2,3,6,7,8-HxCDD	1976	46	79.6 ppt	47.0	19.2-291	100	2-4 ppt	Ryan et al., 1985a	2
Canada	1,2,3,4,6,7,8-HpCDD	1976	46	137 ppt	79	34.4-520	100	2-4 ppt	Ryan et al., 1985a	2
Canada	1,2,3,4,6,7,8,9-OCDD	1976	46	796 ppt	458	202-2961	100	10 ppt	Ryan et al., 1985a	2

See notes at end of Table 3.1u.

Table 3.1r Residue Levels in Human Adipose Tissue (Lipid Weight): Furans

Sample Location	Congener	Year Collected	N	Reported Mean	Reference
Canada	2,3,4,7,8-PCDF	1976	46	17 pg/g	Ryan, 1986
Canada	HxCDF	1976	46	14 pg/g	Ryan, 1986
Canada	1,2,3,4,6,7,8-HpCDF	1976	46	36 pg/g	Ryan, 1986

Table 3.1s Residue Levels in Human Adipose Tissue (Wet Weight): Furans

Sample Location	Congener	Year(s) Collected	N	Reported Mean	SD	Range	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	2,3,4,7,8-PeCDF	1976	6	10.4 ppt				2-4 ppt	Ryan et al., 1985a	2
Ontario	1,2,3,4,7,8 and 1,2,3,6,7,8-HxCDF	1976	6	12.7 ppt				2-4 ppt	Ryan et al., 1985a	2
Ontario	1,2,3,4,6,7,8-HpCDF	1976	6	28.0 ppt				2-4 ppt	Ryan et al., 1985a	2
E. Ontario	2,3,4,7,8-PeCDF	1980	9	18.4 ppt	6.3	11.5-29.5	100	2-4 ppt	Ryan et al., 1985a	2
E. Ontario	1,2,3,4,7,8- and 1,2,3,6,7,8-HxCDF	1980	9	17.3 ppt	6.9	13.6-28.8	89	2-4 ppt	Ryan et al., 1985a	2
E. Ontario	1,2,3,4,6,7,8-HpCDF	1980	9	39.4 ppt	19.6	12.8-67	78	2-4 ppt	Ryan et al., 1985a	2
Canada	2,3,4,7,8-PCDF	1976	46	16.8 ppt	7.6	4.2-45.0	100	2-4 ppt	Ryan et al., 1985a	2
Canada	1,2,3,4,7,8- and 1,2,3,6,7,8-HxCDF	1976	46	17.3 ppt	10.9	ND-71.2	70	2-4 ppt	Ryan et al., 1985a	2
Canada	1,2,3,4,6,7,8-HpCDF	1976	46	32.7 ppt	15.9	ND-110	93	2-4 ppt	Ryan et al., 1985a	2

See notes at end of Table 3.1u.

Table 3.1t Residue Levels in Human Adipose Tissue (Lipid Weight): PCBs

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (µg/g)	Detect. Freq. %	Detect. Limit	Reference	Comments
S. Ontario	1970	29	1.2 ppm		1.0-2.0	1.2			Holdrinet et al., 1977	6, 9, 10, 11
S. Ontario	1971	97	1.7 ppm		ND-10.0	1.7			Holdrinet et al., 1977	6, 9, 10, 11
S. Ontario	1972	126	3.2 ppm		0.6-18.0	3.2			Holdrinet et al., 1977	6, 9, 10, 11
Ontario	1972	59	2.5 ppm		0.7-7.3	2.5			Holdrinet et al., 1977	3, 6, 9, 10, 11
S. Ontario	1973	30	2.4 ppm		0.8-7.2	2.4			Holdrinet et al., 1977	6, 9, 10, 11
Ontario	1973	63	2.59 ppm		0.6-11.0	2.59			Holdrinet et al., 1977	3, 6, 9, 10, 11
S. Ontario	1974	28	1.6 ppm		0.8-2.8	1.6			Holdrinet et al., 1977	6, 9, 10, 11
S.W. Ontario	1976-1977	125	2.2 mg/kg	1.2		2.2	100	50 µg/g	Frank et al., 1988	6, 9, 10, 11
S.W. Ontario	1978-1979	111	2.3 mg/kg	2.0		2.3	100	50 µg/g	Frank et al., 1988	6, 9, 10, 11
S.W. Ontario	1980-1981	125	1.9 mg/kg	1.3		1.9	100	50 µg/g	Frank et al., 1988	6, 9, 10, 11
S.W. Ontario	1983-1986	209	2.1 mg/kg	1.5		2.1	99	50 µg/g	Frank et al., 1988	6, 9, 10, 11
Cornwall	1984	21	2169 ng/g	1423	604-5866	2.169	100	100 ng/g	Williams et al., 1988	1, 7, 10
London	1984	37	2011 ng/g	1115	610-5159	2.011	100	100 ng/g	Williams et al., 1988	1, 7, 10
St. Catharines	1984	17	2418 ng/g	1587	938-6269	2.418	100	100 ng/g	Williams et al., 1988	1, 7, 10
Toronto	1984	7	2224 ng/g	2003	789-6368	2.224	100	100 ng/g	Williams et al., 1988	1, 7, 10
Welland	1984	23	1854 ng/g	2084	745-11 209	1.854	100	100 ng/g	Williams et al., 1988	1, 7, 10
Windsor	1984	36	2309 ng/g	1204	197-5690	2.309	100	100 ng/g	Williams et al., 1988	1, 7, 10
Ontario	1984	141	2136 ng/g	1473	197-11 209	2.136	100	100 ng/g	Williams et al., 1988	1, 7, 10
Alberta	1967-1968	51	ND			ND	0		Kadis et al., 1970	7, 8

See notes at end of Table 3.1u.

Table 3.1u Residue Levels in Human Adipose Tissue (Wet Weight): PCBs

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (µg/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Toronto	1969	50	ND			ND	0	0.05 mg/kg	Ritcey et al., 1973	6, 12
Ottawa	1969	40	ND			ND		0.05 mg/kg	Ritcey et al., 1973	6, 12
Ontario	1972	57	1.070 µg/g	0.658		1.070	100		Mes et al., 1977	7, 8, 10
Ontario	1976	6	1.791 µg/g	1.468		1.791			Mes et al., 1982	7, 8, 10
Ontario	1976	6	0.253 µg/g	0.073		0.253			Mes et al., 1982	7, 8, 13
Kingston	1979-81	91	2950 ng/g	3626	90-28 300	2.950	100	10 ng/g	Williams et al., 1984	1, 7
Ottawa	1980-81	84	2001 ng/g	873	450-4760	2.001	100	10 ng/g	Williams et al., 1984	1, 7
E. Ontario	1980	10	4.03 ppm	6.02	0.65-20.9	4.03	100		Ryan et al., 1985	7, 8, 10
Canada	1969	221	ND			ND		0.05 mg/kg	Ritcey et al., 1973	6, 12
Canada	1972	168	0.907 µg/g	0.817	0.106-6.603	0.907	100		Mes et al., 1977	7, 8, 10
Canada	1976	99	0.944 µg/g	0.902	0.040-6.801	0.944	100		Mes et al., 1982	7, 8, 10
Canada	1976	99	0.307 µg/g	0.272	0.054-2.300	0.307	100		Mes et al., 1982	7, 8, 13
Canada	1976	46	0.95 ppm	0.70	0.16-4.17	0.95	100		Ryan et al., 1985	7, 8, 10

Notes for Adipose Tissue Tables
1. The numerical value for all non-detects was set at one-half of the detection limit for calculating the mean.
2. Arithmetic mean calculated using positive values only .
3. Ontario outside of southern region.
4. Standard error reported instead of standard deviation.
5. Not calculated due to interference.
6. Values not corrected for recovery losses.
7. Did not report whether values were corrected for recovery losses.
8. Did not report how means were calculated.
9. Aroclor 1254 standard.
10. Aroclor 1260 standard.
11. Aroclor mixture standard.
12. Did not report which Arochlor standard was used.
13. Aroclor 1242 standard.
14. Frequency distribution reported.
15. Minimum value not reported.
16. Detection frequency does not include samples where values were not calculated due to interference.
17. Children less than five years old.
18. Pooled sample.

HUMAN TISSUE DATA:
BLOOD

Table 3.2a Residue Levels in Human Blood (whole): Metals

Chemical	Sample Location	Year(s) Collected	N	Mean (Median)	SD	Range	Stand. Mean (µg/g)	Reference	Comments
Mercury	Ontario	1971-1978	6,124			<20-460 ppb		Wheatley, 1979	3a, 6
	Ontario	1979-1982	8,609			<20-304 ppb		Wheatley, 1984	3a, 6
	International	1974-1972	315			<0.005-0.02 mg/L		Iyengar et al, 1978	1b,2,3a,3d,3f,3g
	International		17			0.6-59 µg/L		Iyengar, Woittiez, 1988	1b,2,8,10
Copper	British Columbia	1977	946	(1.11 mg/L)		0.69-1.78	1.05	Subramanian, Meranger, 1983	3a,4,8,9
	United States		116	123 µg/100 g		37-215	1.23	Smith et al., 1976	3e
	International	1950-1974	1941	1.01 mg/L		0.66-1.28	0.953	Iyengar et al, 1978	1a,1b,3a,3b,3c,3d,3e,9
	International		16	0.91 mg/L	0.13	0.8-1.3	0.86	Iyengar, Woittiez, 1988	1a,1b,2,8,10
Cadmium	British Columbia	1977	946	<0.0005 mg/L			<0.0005	Subramanian, Meranger, 1983	3a, 4
	United States		52	0.66 µg/100 g	0.25	0.21-2.66	0.0066	Smith et al., 1976	3e, 5
	International	1969-1973	354	0.0053 mg/L		0.0011-0.0076	0.0053	Iyengar et al, 1978	1a,1b,2,3a,3b,3f,9
	International		53	(1.0 µg/L)		0.3-7.0		Iyengar, Woittiez, 1988	1b,2,10
Zinc	British Columbia	1977	946	(4.3 mg/L)		2.10-6.53	4.1	Subramanian, Meranger, 1983	3a,4,8,9
	International	1951-1974	2,425	7.0 mg/L		4.0-9.3	6.6	Iyengar et al, 1978	1a,1b,2,3d,3e,9
	International		19	(8.0 mg/L)	1.1	4.4-8.6	7.6	Iyengar, Woittiez, 1988	1a,1b,2,8,10
Lead	Ontario	1984	384	0.1042 mg/L	0.0152		0.0993	MacPhersen, 1987	3a,3h,7,9
	Ontario (urban)	1984	200	0.1189 mg/L	0.0139		0.113	MacPhersen, 1987	3a,3h,7,9
	S. Riverdale,Ont	1984	214	0.1389 mg/L	0.0138		0.132	MacPhersen, 1987	3a.3h,7,9
	British Columbia	1977	946	(0.122 mg/L)		0.02-0.4	0.115	Subramanian, Meranger, 1983	3a,4,8,9
	United States		116	15.7 µg/100g	6.33	3.0-37.0	0.157	Smith et al., 1976	3e, 5
	International	1953-1973	17,335	0.214 mg/L		0.088-0.40	0.202	Iyengar et al, 1978	1a,1b,2,3a,3b,3c,3d,3e,9
	International		95	(123 µg/L)		8-260		Iyengar, Woittiez, 1988	1b,2,10
Arsenic	International	1944-1974	144			0.0025-0.19 mg/L		Iyengar et al, 1978	3c,3d,3f,3g
	International		8	(5 µg/L)		2-23		Iyengar, Woittiez, 1988	1b,2,10

See notes at end of Table 3.2d

Table 3.2b Residue Levels in Human Blood (Serum): Nickel

Sample Location	Year(s) Collected	N	Mean	SD	Range	Stand. Mean (µg/g)	Reference	Comments
International	1956-71	295	29.7 µg/L		0.0078-0.0580	0.0297	Iyengar et al, 1978	1a,1b,2,3a,3b,3e,10
Sudbury, Ont	1971	25	4.6 µg/L	1.4	2.0-7.3	0.0045	Mcneely et al, 1972	3a,11
Hartford, Conn.	1971	26	2.6 µg/L	1.0	0.8-5.2	0.0025	Mcneely et al, 1972	3a,11
Sudbury, Ont.		22	0.6 µg/L	0.3	0.2 - 1.3	0.6	Hopfer et al, 1987	3a,9,12
Hartford, Conn.		43	0.2 µg/L	0.2	<0.05 - 1.0	0.2	Hopfer et al, 1987	3a,9,12
International		2			0.05-1.3 µg/L		Iyengar, Woittiez, 1988	1b,2,10

See notes at end of Table 3.2d

Table 3.2c Residue Levels in Human Blood (plasma): Arsenic

Chemical	Sample Location	Year(s) Collected	N	Mean	SD	Range	Reference	Comments
Arsenic	International	1967-1983		0.452-1.7 mg/mL		0.088-1.82	Versieck, 1985	1a,1b,2,3f

See notes at the end of Table 3.2d

Table 3.2d Residue Levels in Human Blood (whole): Mercury

Sample Location	Year Collected	N	Number and Frequency of Analyses for Concentration Intervals							Reference	Comments
			<20 ppb	20-99 ppb	100-199 ppb	200-299 ppb	300-399 ppb	400-499 ppb	500-700 ppb		
Ontario	1971-1978	6,124	4,566 (74.56%)	1,359 (22.19%)	157 (2.56%)	28 (0.46%)	7 (0.11%)	5 (0.08%)	2 (0.03%)	Wheatley, 1979	3a
Ontario	1979-1982	8,609	7,161 (83.18%)	1,397 (16.23%)	47 (0.55%)	3 (0.03%)	1 (0.01%)			Wheatley, 1984	3a
Manitoba	1979-1982	5,274	4,567 (86.6%)	698 (13.23%)	8 (0.15%)	1 (0.02%)				Wheatley, 1984	3a
Quebec	1979-1982	2,410	1,161 (48.17%)	1,229 (51.00%)	20 (0.83%)					Wheatley, 1984	3a

Notes for Human Tissue Data on Blood Levels of Various Metals

1a. The mean column has a value that is the grand mean.
1b. The range column has values that are the range of means.
2. Various locations are used in this study. Reference compilation consisted of primarily adult values. The "Years Collected" column represents date of publication rather than date of sample collection.
3. Analytical Technique
3a. Atomic Absorption Spectrometry.
3b. Arc Emission Spectrometry / Flame Emission Spectrometry.
3c. Polarography.
3d. Solution Absorption Spectrometry.
3e. X-Ray Fluorescence.
3f. Neutron Activation.
3g. Mass Spectrometry.
3h. Extraction Colorimetry.
4. B.C. children that were potentially exposed were examined in this study. They were living in an area near a copper mine-mill complex.
5. Children from the United States were used for this study, ages 2 months to 13 years, with no known exposure to cadmium, lead, or copper.
6. This study included Indian and Inuit populations, all ages, and both genders. Hair mercury values were converted to blood mercury values for part of this data.
7. This study had children ages 1-6 years, both genders.
8. The mean value in this case was actually a weighted mean value.
9. Standard mean values were calculated using density values of whole blood, plasma and serum of 1.06, 1.028, and 1.028, respectively.
10. The number column actually represents number of sets of data.
11. This study involved healthy adult hospital workers, male and female, average age 31.0 ± 11.0 years in Sudbury. The Hartford subjects included both genders, average age 32.4 ± 12.0 years. Both of these groups were not occupationally exposed.
12. This study involved healthy adult hospital workers, 82 percent female, from Sudbury. The 43 Hartford residents were healthy hospital workers, 49 percent female.

HUMAN MILK DATA

Table 3.3a Residue Levels in Human Milk (Milk Fat): Chlordane and Related Species

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Alberta	cis/trans chlordane	1977-78	33	NC			NC		0.001 ppm	Currie et al., 1979	6, 8
Canada	τ-chlordane	1982	210	10 ng/g		ND-68	10	73		Mes et al., 1986	2, 7
Canada	α-chlordane	1982	210	27 ng/g		ND-84	27	56		Mes et al., 1986	2, 7
Canada	oxychlordane	1982	210	27 ng/g		Max. 109	27	100		Mes et al., 1986	2, 7, 16
Canada	oxychlordane	1987	18	35 ng/g			35	100		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3x.

Table 3.3b . Residue Levels in Human Milk (Whole Milk): Chlordane and Related Species

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	oxychlordane	1975	35	1 ng/g			1		1 ng/g	Mes and Davies, 1979	2, 6
Ontario	chlordane	1975-85	200	ND			ND		0.15 µg/kg	Frank et al., 1988	6
Ontario	α-chlordane	1982	75	1 ng/g			1			Mes et al., 1986	2, 7
Ontario	τ-chlordane	1982	75	trace			NC			Mes et al., 1986	2, 7
Ontario	oxychlordane	1982	75	1 ng/g			1			Mes et al., 1986	2, 7
Canada	oxychlordane	1975	100	1 ng/g		ND - 2	1	77	1 ng/g	Mes and Davies, 1979	2, 6
Canada	α-chlordane	1982	210	1 ng/g		ND - 4	1	56		Mes et al., 1986	2, 7
Canada	τ-chlordane	1982	210	trace		ND - 2	NC	73		Mes et al., 1986	2, 7
Canada	oxychlordane	1982	210	1 ng/g		Max. 2	1	100		Mes et al., 1986	2, 7, 16
Canada	oxychlordane	1987	18	0.7 ng/g			0.7	100		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3x.

Table 3.3c Residue Levels in Human Milk (Milk Fat): Dieldrin and Aldrin

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	Dieldrin	1967-68	25	0.284 mg/kg	0.291	0.05-1.53	284	98	0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	Dieldrin	1969-70	48	0.09 ppm		<0.01-0.25	90			Holdrinet et al., 1977	6, 8
Ontario	Dieldrin	1971-72	34	0.04 ppm		<0.01-0.17	40			Holdrinet et al., 1977	6, 8
Ontario	Dieldrin	1973-74	19	0.04 ppm		<0.01-0.08	40			Holdrinet et al., 1977	6, 8
Alberta	Dieldrin	1966-70	59	0.18 ppm		ND-4.66	180	39	0.001 ppm	Currie et al., 1979	6, 8
Alberta	Dieldrin	1977-78	33	0.025 ppm		ND-0.081	25	97	0.001 ppm	Currie et al., 1979	6, 8
Quebec	Aldrin	1978-79	154	0.041 mg/kg	0.068	0-0.74	41	98		Dillon et al., 1981	3, 7, 8, 14
Canada	Dieldrin	1982	210	27 ng/g		ND-202	27	95		Mes et al., 1986	2, 7
Canada	Dieldrin	1987	18	21 ng/g			21	89		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3a.

Table 3.d Residue Levels in Human Milk (Whole Milk): Dieldrin and Aldrin

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	Dieldrin	1967-68	25	0.008 mg/kg	0.011	0.002-0.060	8	98	0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	Dieldrin	1975	35	2 ng/g			2		1 ng/g	Mes and Davies, 1979	2, 6
Ontario	Dieldrin	1975	15	0.54 µg/kg	0.27		0.54		0.15 µg/kg	Frank et al., 1988	6, 8
Ontario	Dieldrin	1978	127	0.54 µg/kg	0.35		0.54		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	Dieldrin	1979	15	0.36 µg/kg	0.27		0.36		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	Dieldrin	1980-81	12	0.30 µg/kg	0.21		0.30		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	Dieldrin	1982	75	1 ng/g			1			Mes et al., 1986	2, 7
Ontario	Dieldrin	1983-84	13	<0.15 µg/kg			<0.15		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	Dieldrin	1985	18	<0.10 µg/kg			<0.10		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Canada	Dieldrin	1975	100	2 ng/g		ND-6	2	84	1 ng/g	Mes and Davies, 1979	2, 6
Quebec	Aldrin	1978-79	154	0.001 mg/kg	0.003		1	98		Dillon et al., 1981	7, 8
Canada	Dieldrin	1982	210	1 ng/g		ND-8	1	95		Mes et al., 1986	2, 7
Canada	Dieldrin	1987	18	0.4 ng/g			0.4	89		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3a.

Table 3.3e Residue Levels in Human Milk (Milk Fat): DDT and Related Species

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (µg/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	p,p'-DDE	1967-68	25	3.743 mg/kg	2.461	0.92-11.10	3.743	100	0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	p,p'-DDT	1967-68	25	1.187 mg/kg	0.982	0.42- 3.55	1.187	100	0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	o,p'-DDT	1967-68	25	0.268 mg/kg	0.150	0.04- 0.69	0.268	93	0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	p,p'-TDE	1967-68	25	0.182 mg/kg	0.121	0.04- 0.54	0.182	95	0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	Total DDT	1967-68	25	5.339 mg/kg	3.340	1.65-17.28	5.399		0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	Total DDT	1969-70	48	3.48 ppm		0.11-11.4	3.48			Holdrinet et al., 1977	6, 8, 13
Ontario	Total DDT	1971-72	34	3.48 ppm		0.33-10.8	3.48			Holdrinet et al., 1977	6, 8, 13
Ontario	Total DDT	1973-74	19	1.30 ppm		0.22- 2.58	1.30			Holdrinet et al., 1977	6, 8, 13
Alberta	p,p'-DDE	1966-70	59	2.23 ppm		0.173-8.12	2.23	100	0.001 ppm	Currie et al., 1979	6, 8
Alberta	p,p'-DDT	1966-70	59	1.14 ppm		ND-11.25	1.14	97	0.001 ppm	Currie et al., 1979	6, 8
Alberta	o,p'-DDT	1966-70	59	0.003 ppm		ND-0.072	0.003	5	0.001 ppm	Currie et al., 1979	6, 8
Alberta	p,p'-TDE	1966-70	59	0.151 ppm		ND-1.65	0.151	83	0.001 ppm	Currie et al., 1979	6, 8
New Brunswick	p,p'-DDE	1972	6	2.61 ppm	1.31	1.12-4.78	2.61	100	0.003 µg/g	Musial et al., 1974	2, 7
New Brunswick	p,p'-DDT	1972	6	0.96 ppm	0.77	0.39-2.11	0.97	100	0.002 µg/g	Musial et al., 1974	2, 7
Nova Scotia	p,p'-DDE	1972	9	1.00 ppm	0.77	0.70-2.83	1.00	100	0.003 µg/g	Musial et al., 1974	2, 7
Nova Scotia	p,p'-DDT	1972	9	0.061 ppm	0.23	trace-0.98	0.061	100	0.002 µg/g	Musial et al., 1974	2, 7
Alberta	p,p'-DDE	1977-78	33	1.09 ppm		0.250-5.10	1.09	100	0.001 ppm	Currie et al., 1979	6, 8
Alberta	p,p'-DDT	1977-78	33	0.437 ppm		trace-0.35	0.437	100	0.001 ppm	Currie et al., 1979	6, 8
Alberta	o,p'-DDT	1977-78	33	0.031 ppm		ND-0.160	0.031	70	0.001 ppm	Currie et al., 1979	6, 8
Alberta	p,p'-TDE	1977-78	33	0.023 ppm		ND-0.340	0.023	48	0.001 ppm	Currie et al., 1979	6, 8
Quebec	p,p'-DDE	1978-79	154	0.883 mg/kg	0.773	0.01-6.79	0.883	99		Dillon et al., 1981	3, 7, 8, 14
Quebec	p,p'-DDT	1978-79	154	0.204 mg/kg	0.262	0-2.51	0.204	99		Dillon et al., 1981	3, 7, 8, 14
Quebec	Total DDT	1978-79	154	1.087 mg/kg	0.880	0.01-6.81	1.087	99		Dillon et al., 1981	3, 7, 8, 14
Canada	p,p'-DDE	1982	210	911 ng/g		Max. 5800	0.911	100		Mes et al., 1986	2, 7, 16
Canada	p,p'-DDT	1982	210	80 ng/g		ND-450	0.080	96		Mes et al., 1986	2, 7
Canada	o,p'-DDT	1982	210	12 ng/g		ND- 58	0.012	26		Mes et al., 1986	2, 7
Canada	p,p'-TDE	1982	210	27 ng/g		ND-113	0.027	64		Mes et al., 1986	2, 7
Canada	p,p'-DDE	1987	18	739 ng/g			0.739	100		Davies & Mes, 1987	2, 7, 15
Canada	p,p'-DDT	1987	18	61 ng/g			0.061	94		Davies & Mes, 1987	2, 7, 15
Canada	o,p'-DDT	1987	18	19 ng/g			0.019	28		Davies & Mes, 1987	2, 7, 15
Canada	p,p'-TDE	1987	18	18 ng/g			0.018	72		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3s

Table 3.3f Residue Levels in Human Milk (Whole Milk): DDT and Related Species

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	p,p'-DDE	1967-68	25	0.131 ppm	0.164	0.022-0.490	131			Ritcey et al., 1972	7, 8
Ontario	p,p'-DDT	1967-68	25	0.038 ppm	0.042	0.008-0.217	38			Ritcey et al., 1972	7, 8
Ontario	o,p'-DDT	1967-68	25	0.007 ppm	0.005	0.001-0.027	7			Ritcey et al., 1972	7, 8
Ontario	p,p'-TDE	1967-68	25	0.006 ppm	0.005	0.001-0.022	6			Ritcey et al., 1972	7, 8
Ontario	Total DDT	1967-68	25	0.169 ppm	0.164	0.04-0.68	169			Ritcey et al., 1972	7, 8
Ontario	Total DDT	1975	15	24.0 µg/kg	33.0		24	100	0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	p,p'-DDE	1975	35	34 ng/g			34		1 ng/g	Mes and Davies, 1979	2, 6
Ontario	p,p'-DDT	1975	35	6 ng/g			6		1 ng/g	Mes and Davies, 1979	2, 6
Ontario	o,p'-DDT	1975	35	6 ng/g			6		1 ng/g	Mes and Davies, 1979	2, 6
Ontario	Total DDT	1978	127	27.3 µg/kg	27.5		27.3	100	0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	Total DDT	1979	15	25.1 µg/kg	22.1		25.1	100	0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	Total DDT	1980-81	12	30.9 µg/kg	15.8		30.9	100	0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	p,p'-DDE	1982	75	37 ng/g			37			Mes et al., 1986	2, 7
Ontario	p,p'-DDT	1982	75	4 ng/g			4			Mes et al., 1986	2, 7
Ontario	o,p'-DDT	1982	75	1 ng/g			1			Mes et al., 1986	2, 7
Ontario	p,p'-TDE	1982	75	1 ng/g			1			Mes et al., 1986	2, 7
Ontario	Total DDT	1983-84	13	16.9 µg/kg	19.4		16.9	100	0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	Total DDT	1985	18	22 µg/kg	21		22	100	0.15 µg/kg	Frank et al., 1988	6, 8, 13

See notes at end of Table 3.3a

Table 3.3f Continued.

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Canada	p,p'-DDE	1970	90	56 ng/g			56			Mes et al, 1984	2, 7
Canada	p,p'-DDT	1970	90	15 ng/g			15		1 ppb	Mes and Davies, 1979	2, 6
Canada	o,p'-DDT	1970	90	3 ng/g			3			Mes and Davies, 1979	2, 6
Canada	p,p'-TDE	1970	90	3 ng/g			3			Mes and Davies, 1979	2, 6
New Brunswick	p,p'-DDE	1972	6	0.035 ppm	0.018	0.017–0.068	35	100	0.003 µg/g	Musial et al., 1974	2, 7
New Brunswick	p,p'-DDT	1972	6	0.013 ppm	0.009	0.006–0.030	13	100	0.002 µg/g	Musial et al., 1974	2, 7
Nova Scotia	p,p'-DDE	1972	9	0.019 ppm	0.010	0.009–0.040	19	100	0.003 µg/g	Musial et al., 1974	2, 7
Nova Scotia	p,p'-DDT	1972	9	0.006 ppm	0.002	trace–0.011	6	100	0.002 µg/g	Musial et al., 1974	2, 7
Canada	p,p'-DDE	1975	100	35 ng/g		Max. 144		100	1 ng/g	Mes and Davies, 1979	2, 6, 16
Canada	p,p'-DDT	1975	100	6 ng/g		Max. 21	6	100	1 ng/g	Mes and Davies, 1979	2, 6, 16
Canada	o,p'-DDT	1975	100	3 ng/g		ND - 48	3	32	1 ppb	Mes and Davies, 1979	2, 6
Quebec	p,p'-DDE	1978-79	154	0.032 mg/kg	0.028		32	99		Dillon et al., 1981	7, 8
Quebec	p,p'-DDT	1978-79	154	0.007 mg/kg	0.009		7	99		Dillon et al., 1981	7, 8
Quebec	Total DDT	1978-79	154	0.039 mg/kg	0.031		39	99		Dillon et al., 1981	7, 8
Canada	p,p'-DDE	1982	210	34 ng/g		Max. 268	34	100		Mes et al., 1986	2, 7, 16
Canada	p,p'-DDT	1982	210	3 ng/g		ND - 29	3	96		Mes et al., 1986	2, 7
Canada	o,p'-DDT	1982	210	trace		ND - 2	NC	26		Mes et al., 1986	2, 7
Canada	p,p'-TDE	1982	210	1 ng/g		ND - 4	1	64		Mes et al., 1986	2, 7
Canada	p,p'-DDE	1987	18	14.2 ng/g			14.2	100		Davies & Mes, 1987	2, 7, 15
Canada	p,p'-DDT	1987	18	1.1 ng/g			1.1	94		Davies & Mes, 1987	2, 7, 15
Canada	o,p'-DDT	1987	18	0.4 ng/g			0.4	28		Davies & Mes, 1987	2, 7, 15
Canada	p,p'-TDE	1987	18	0.3 ng/g			0.3	72		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3a

Table 3.3g Residue Levels in Human Milk (Milk Fat): Hexachlorobenzene

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Detect. Freq. %	Detect. Limit	Reference	Comments
Ontario	1973-74	14	0.10 mg/kg		ND-0.25	100			Noldrinet et al., 1977	6, 8
Alberta	1977-78	33	0.091 ppm		Trace-5.13	91	94		Currie et al., 1979	6, 8
Canada	1982	210	54 ng/g		Max. 256	54	100	1 ng/g	Mes et al., 1986	2, 7, 16
Canada	1987	18	52 ng/g			52	94		Davies & Mes, 1988	2, 7, 15

See notes at end of Table 3.3s

Table 3.3h Residue Levels in Human Milk (Whole Milk): Hexachlorobenzene

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Detect. Freq. %	Detect. Limit	Reference	Comments
Ontario	1975	35	2 ng/g			2		1 ng/g	Mes & Davies, 1979	2, 6
Ontario	1982	75	2 mg/g			2	100	1 ng/g	Mes et al., 1986	2, 7
Ontario	1978	127	0.51 µg/kg	1.31		0.51		0.15 µg/kg	Frank et al., 1988	6, 8
Ontario	1979	15	0.39 µg/kg	0.29		0.39		0.15 µg/kg	Frank et al., 1988	6, 8
Ontario	1980-81	12	0.28 µg/kg	0.21		0.28		0.15 µg/kg	Frank et al., 1988	6, 8
Ontario	1983-84	13	0.52 µg/kg	0.61		0.52		0.15 µg/kg	Frank et al., 1988	6, 8
Ontario	1985	18	0.26 µg/kg	0.42		0.26		0.15 µg/kg	Frank et al., 1988	6, 8
Canada	1975	100	2 ng/g		Max. 21	2	81	1 ng/g	Mes & Davies, 1979	2, 6, 16
Canada	1982	210	2 mg/g		Max. 9	2	100	1 ng/g	Mes et al, 1986	2, 7, 16
Canada	1988	18	1.0 ng/g				94		Davies & Mes, 1988	2, 7, 15

See notes at end of Table 3.3s

Table 3.3i Residue Levels in Human Milk (Milk Fat): HCH Isomers

Sample Location	Isomer	Year(s) Collected	n	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	γ-HCH	1967-68	25	0.071 mg/kg	0.070	<0.01-0.32	71	81	0.001 mg/kg	Ritcey et al., 1972	7, 8
Alberta	α-HCH	1966-70	59	0.107 ppm		ND-0.733	107	37	0.001 ppm	Currie et al., 1979	6, 8
Alberta	γ-HCH	1966-70	59	0.006 ppm		ND-0.340	6	3	0.001 ppm	Currie et al., 1979	6, 8
Alberta	α-HCH	1977-78	33	0.002 ppm		ND-0.016	2	76	0.001 ppm	Currie et al., 1979	6, 8
Alberta	β-HCH	1977-78	33	0.232 ppm		0.009-0.393	232	100	0.001 ppm	Currie et al., 1979	6, 8
Alberta	γ-HCH	1977-78	33	ND			ND	0	0.001 ppm	Currie et al., 1979	6, 8
Quebec	γ-HCH	1978-79	154	0.047 mg/kg	0.131	ND-1.56	47	95		Dillon et al., 1981	3, 7, 8, 14
Canada	α-HCH	1982	210	7 ng/g		ND-62	7	99		Mes et al., 1986	2, 7
Canada	β-HCH	1982	210	214 ng/g		Max. 3276	214	100		Mes et al., 1986	2, 7, 16
Canada	γ-HCH	1982	210	5 ng/g		ND-98	5	68		Mes et al., 1986	2, 7
Canada	α-HCH	1987	18	5 ng/g			5	100		Davies & Mes, 1987	2, 7, 15
Canada	β-HCH	1987	18	22 ng/g			22	100		Davies & Mes, 1987	2, 7, 15
Canada	γ-HCH	1987	18	7 ng/g			7	44		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3s

Table 3.3j Residue Levels in Human Milk (Whole Milk): HCH Isomers

Sample Location	Isomer	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	γ-HCH	1967-68	25	0.002 mg/kg	0.003	<0.001-0.013	2	81	0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	β-HCH	1975	35	3 ng/g			3		1 ng/g	Mes and Davies, 1979	2, 6
Ontario	γ-HCH	1975-85	100	ND				0	15 ng/L	Frank et al., 1988	
Ontario	α-HCH	1982	75	trace			NC			Mes et al., 1986	2, 7
Ontario	β-HCH	1982	75	8 ng/g			8			Mes et al., 1986	2, 7
Ontario	γ-HCH	1982	75	trace			NC			Mes et al., 1986	2, 7
Canada	β-HCH	1975	100	2 ng/g		ND - 21	2	91	1 ng/g	Mes and Davies, 1979	2, 6
Quebec	γ-HCH	1978-79	154	0.002 mg/kg	0.0001		2	95		Dillon et al., 1981	7, 8
Canada	α-HCH	1982	210	trace		ND-1 ng/g	NC	99		Mes et al., 1986	2, 7
Canada	β-HCH	1982	210	8 ng/g		Max. 39	8	100		Mes et al., 1986	2, 7, 16
Canada	γ-HCH	1982	210	trace		ND-2 ng/g	NC	68		Mes et al., 1986	2, 7
Canada	α-HCH	1987	18	0.1 ng/g			0.1	100		Davies & Mes, 1987	2, 7, 15
Canada	β-HCH	1987	18	0.4 ng/g			0.4	100		Davies & Mes., 1987	2, 7, 15
Canada	γ-HCH	1987	18	0.1 ng/g			0.1	66		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3a

Table 3.3k Residue Levels in Human Milk (Milk Fat): Heptachlor Epoxide

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	1967-68	25	0.169 mg/kg	0.118	0.03-0.50	169	88	0.001 mg/kg	Ritcey et al., 1972	7, 8
Alberta	1966-70	59	0.002 ppm		ND-0.060	2	5	0.001 ppm	Currie et al., 1979	6, 8
Alberta	1977-78	33	0.028 ppm		ND-0.113	25	94		Currie et al., 1979	6, 8
Canada	1982	210	15 ng/g		ND-191	15	62		Mes et al., 1986	2, 7
Canada	1987	18	11 ng/g			11	61		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3a

Table 3.3l Residue Levels in Human Milk (Whole Milk): Heptachlor Epoxide

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	1967-68	25	0.005 mg/kg	0.005	0.001-0.020	5	88	0.001 mg/kg	Ritcey et al., 1972	7, 8
Ontario	1975	35	1 ng/g			1		1 ng/g	Mes and Davies, 1979	2, 6
Ontario	1975	15	0.60 µg/kg	0.45		0.6		0.15 µg/kg	Frank et al., 1988	6, 8
Ontario	1978	127	0.34 µg/kg	0.60		0.34		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	1979	15	0.22 µg/kg	0.16		0.22		0.15 µg/kg	Frank et al., 1988	6, 8, 1
Ontario	1980-81	12	0.16 µg/kg	0.15		0.16		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	1982	75	1 ng/g			1			Mes et al., 1986	2, 7
Ontario	1983-84	13	<0.15 µg/kg			<0.15		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Ontario	1985	18	<0.10 µg/kg			<0.10		0.15 µg/kg	Frank et al., 1988	6, 8, 13
Canada	1975	100	1 ng/g		ND-3	1	69	1 ng/g	Mes and Davies, 1979	2, 6
Canada	1982	210	trace		ND-7 ng/g	NC	62		Mes et al., 1986	2, 7
Canada	1987	18	0.2 ng/g			0.2	61		Davies and Mes, 1987	2, 7, 15

See notes at end of Table 3.3a

Table 3.3m Residue Levels in Human Milk (Milk Fat): Mirex and Photomirex

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Alberta	Mirex	1977-78	33	NC			NC		0.001 ppm	Currie et al., 1979	6
Canada	Photomirex	1982	210	8 ng/g		Max. 40	8	100		Mes et al., 1986	2, 7, 16
Canada	Photomirex	1987	18	13 ng/g			13	94		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3s

Table 3.3n Residue Levels in Human Milk (Whole Milk): Mirex and Photomirex

Sample Location	Species	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	Mirex	1975-85	200	ND				0	0.15 µg/kg	Frank et al., 1988	
Ontario	Photomirex	1982	75	trace			NC			Mes et al., 1986	2, 7
Canada	Mirex	1975	14	NC			NC	21		Mes et al., 1978	
Canada	Photomirex	1982	210	trace		trace - 2 ng/g	NC	100		Mes et al., 1986	2, 7
Canada	Photomirex	1987	18	0.2 ng/g			0.2	94		Davies & Mes, 1987	2, 7, 15

See notes at end of Table 3.3s

Table 3.3p Residue Levels in Human Milk (Milk Fat): Dioxins and Dibenzofurans

Sample Location	Congener	Year Collected	N²⁷	Reported Mean (pg/g)	Reference
Canada	2,3,7,8-TCDD	1981	200	4.5	Ryan, 1986
Canada	1,2,3,7,8-PCDD	1981	200	10	Ryan, 1986
Canada	HxCDD	1981	200	69	Ryan, 1986
Canada	1,2,3,4,6,7,8-HpCDD	1981	200	138	Ryan, 1986
Canada	OCDD	1981	200	277	Ryan, 1986
Canada	2,3,7,8-TCDF	1981	200	4.2	Ryan, 1986
Canada	2,3,4,7,8-PCDF	1981	200	12	Ryan, 1986
Canada	HxCDF	1981	200	12	Ryan, 1986
Canada	1,2,3,4,6,7,8-HpCDF	1981	200	13	Ryan, 1986

See notes at end of Table 3.3s

Table 3.3q Residue Levels in Human Milk (Whole Milk): Dioxins and Dibenzofurans

Sample Location	Congener	Year Collected	N''	Reported Mean (pg/g)	Reference
Canada	2,3,7,8-TCDD	1981	200	0.17	Ryan, 1986
Canada	1,2,3,7,8-PCDD	1981	200	0.38	Ryan, 1986
Canada	HxCDD	1981	200	2.6	Ryan, 1986
Canada	1,2,3,4,6,7,8-HpCDD	1981	200	5.3	Ryan, 1986
Canada	OCDD	1981	200	10.3	Ryan, 1986
Canada	2,3,7,8-TCDF	1981	200	0.16	Ryan, 1986
Canada	2,3,4,7,8-PCDF	1981	200	0.44	Ryan, 1986
Canada	HxCDF	1981	200	0.46	Ryan, 1986
Canada	1,2,3,4,6,7,8-HpCDF	1981	200	0.50	Ryan, 1986

See notes at end of Table 3.3s.

Table 3.3r Residue Levels in Human Milk (Milk Fat): PCBs

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (µg/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	1969-70	43	1.0 ppm		0.7-1.2	1			Holdrinet et al., 1977	6, 9, 18
Ontario	1971-71	34	1.2 ppm		0.2-3.0	1.2			Holdrinet et al., 1977	6, 9, 18
Ontario	1973-74	19	1.2 ppm		0.1-2.5	1.2			Holdrinet et al., 1977	6, 9, 18
New Brunswick	1972	6	1.53 ppm	0.37	1.07-2.10	1.53	100	0.01 µg/g	Musial et al., 1974	2, 6, 9
Nova Scotia	1972	7	1.86 ppm	0.52	trace-2.46	1.86	100	0.01 µg/g	Musial et al., 1974	2, 6, 9
Alberta	1977-78	33	0.085 ppm		trace-0.751	0.085	100	0.02 ppm	Currie et al., 1979	6, 8, 12
Quebec	1978-79	154	0.837 mg/kg	0.529	ND-4.34	0.837	99		Dillon et al., 1981	3, 7, 8, 9, 14
Canada	1982	210	697 ng/g		Max. 3022	0.697	100		Mes et al., 1986	2, 7, 10, 16

See notes at end of Tabe 3.3s.

Table 3.3s Residue Levels in Human Milk (Whole Milk): PCBs

Sample Location	Year(s) Collected	N	Reported Mean	SD	Range	Stand. Mean (ng/g)	Det. Freq. %	Detect. Limit	Reference	Comments
Ontario	1975	35	17 ng/g			17		1 ppb	Mes and Davies, 1979	2, 6, 10
Ontario	1975	15	25 µg/kg	12		25		2 µg/kg	Frank *et al.*, 1988	6, 8, 9, 10, 11, 13
Ontario	1978	275	21 µg/kg	14		21		2 µg/kg	Frank *et al.*, 1988	6, 8, 9, 10, 11, 13
Ontario	1979	15	33 µg/kg	14		33		2 µg/kg	Frank *et al.*, 1988	6, 8, 9, 10, 11, 13
Ontario	1980-81	12	26 µg/kg	16		26		2 µg/kg	Frank *et al.*, 1988	6, 8, 9, 10, 11, 13
Ontario	1982	75	27 ng/g			27	100		Mes *et al.*, 1986	2, 7, 10
Ontario	1983-84	13	25 µg/kg	23		25		2 µg/kg	Frank *et al.*, 1988	6, 8, 9, 10, 11, 13
Ontario	1985	18	23 µg/kg	17		23		2 µg/kg	Frank *et al.*, 1988	6, 9, 9, 10, 11, 13
Canada	1970	90	6 ng/g			6			Mes *et al.*, 1986	2, 7, 10
New Brunswick	1972	6	0.022 ppm	0.007	0.015-0.030	22	100	0.01 µg/g	Musial *et al.*, 1974	2, 7, 9
Nova Scotia	1972	9	0.018 ppm	0.007	trace-0.032	18	100	0.01 µg/g	Musial *et al.*, 1974	2, 7, 9
Canada	1975	100	12 ng/g		ND - 68	12	98	1 ppb	Mes and Davies, 1979	2, 6, 10
Quebec	1978-79	154	0.029 mg/kg	0.019		29	99		Dillon *et al.*, 1981	7, 8, 9
Canada	1982	210	26 ng/g		Max. 80	26	100		Mes *et al.*, 1986	2, 7, 10, 16
Canada	1987	18	12.4 ng/g			12.4			Davies & Mes, 1987	2, 7, 11, 15

Notes for Human Milk Tables

1. The numerical value for all non-detects was set at one-half of the detection limit for calculating the mean.
2. Arithmetic mean calculated using positive values only.
3. Residue levels on a milk-fat basis were calculated based on 3.5% milk-fat content.
4. Standard error reported instead of standard deviation.
5. Not calculated due to interference.
6. Values not corrected for recovery losses.
7. Did not report whether values were corrected for recovery losses.
8. Did not report how means were calculated.
9. Aroclor 1254 standard.
10. Aroclor 1260 standard.
11. Aroclor mixture standard.
12. Did not report which Aroclor standard was used.
13. Frequency distribution reported.
14. Mode reported
15. Study population was Indigenous Canadian population.
16. Minimum value not reported.
17. Pooled sample.

HUMAN TISSUE DATA:
OTHER TISSUES

Table 3.4a Residue Levels in Human Kidney Tissue (Wet Weight): Metals

Chemical	Sample Location	N	Reported Median	Range	Det. Freq. %	Detect. Limit	Reference	Comments
Cadmium	Ottawa-Hull	72		Max. 80 ppm			Méranger et al., 1981	1, 5
Cadmium	Kingston	42	31.8 mg/kg	5.1-91.1	100	0.02 mg/kg	Subramanian and Méranger, 1982	1, 6
Cadmium	Kingston	75	31.0 mg/kg	5.1-109.0	100	0.02 mg/kg	Subramanian et al., 1985	1, 6
Cadmium	Ottawa	64	30.1 mg/kg	4.8-96.0	100	0.02 mg/kg	Subramanian et al., 1985	1, 6
Cadmium	Kingston	39	16.0 mg/kg	2.8-53.8	100	0.02 mg/kg	Subramanian and Méranger, 1982	2, 6
Cadmium	Kingston	71	16.7 mg/kg	1.0-71.5	100	0.02 mg/kg	Subramanian et al., 1985	2, 6
Cadmium	Ottawa	62	15.1 mg/kg	2.2-97.5	100	0.02 mg/kg	Subramanian et al., 1985	2, 6
Copper	Kingston	42	2.2 mg/kg	<1-4.6	100	0.08 mg/kg	Subramanian and Méranger, 1982	1, 6
Copper	Kingston	74	2.4 mg/kg	1.0-5.1	100	0.08 mg/kg	Subramanian et al., 1985	1, 6
Copper	Ottawa	64	2.4 mg/kg	1.6-4.9	100	0.08 mg/kg	Subramanian et al., 1985	1, 6
Copper	Kingston	39	2.1 mg/kg	1.1-7.1	100	0.08 mg/kg	Subramanian and Méranger, 1982	2, 6
Copper	Kingston	76	2.3 mg/kg	1.0-15.9	100	0.08 mg/kg	Subramanian et al., 1985	2, 6
Copper	Ottawa	63	1.9 mg/kg	0.8-5.2	100	0.08 mg/kg	Subramanian et al., 1985	2, 6
Lead	Kingston	76	≤0.1 mg/kg	≤0.1-0.8		0.1 mg/kg	Subramanian et al., 1985	1, 6
Lead	Ottawa	66	≤0.1 mg/kg	≤0.1-0.9		0.1 mg/kg	Subramanian et al., 1985	1, 6
Lead	Kingston	76	≤0.1 mg/kg	≤0.1-1.3		0.1 mg/kg	Subramanian et al., 1985	2, 6
Lead	Ottawa	66	≤0.1 mg/kg	≤0.1-0.8		0.1 mg/kg	Subramanian et al., 1985	2, 6
Mercury	Kingston	72	0.17 mg/kg	0.01-1.18		0.002 mg/kg	Subramanian et al., 1985	1, 6
Mercury	Ottawa	65	0.28 mg/kg	0.01-1.92		0.002 mg/kg	Subramanian et al., 1985	1, 6
Mercury	Kingston	71	0.16 mg/kg	0.01-1.26		0.002 mg/kg	Subramanian et al., 1985	2, 6
Mercury	Ottawa	62	0.22 mg/kg	0.01-1.34		0.002 mg/kg	Subramanian et al., 1985	2, 6
Zinc	Kingston	42	44 mg/kg	16-110		0.2 mg/kg	Subramanian and Méranger. 1982	1, 6
Zinc	Kingston	71	45 mg/kg	16-145		0.2 mg/kg	Subramanian et al., 1985	1, 6

See notes at end of Table 3.4 d.

Table 3.4a Continued

Chemical	Sample Location	N	Reported Median	Range	Det. Freq. %	Detect. Limit	Reference	Comments
Zinc	Ottawa	64	46 mg/kg	18-160	100	0.02 mg/kg	Subramanian et *al.*, 1985	1, 6
Zinc	Kingston	39	32 mg/kg	13-62	100	0.02 mg/kg	Subramanian et *al.*, 1985	2, 6
Zinc	Kingston	75	35 mg/kg	14-156	100	0.02 mg/kg	Subramanian et *al.*, 1985	2, 6
Zinc	Ottawa	61	30 mg/kg	11-142	100	0.02 mg/kg	Subramanian et *al.*, 1985	2, 6

Table 3.4b Residue Levels in Human Kidney Tissue (Lipid Weight): Organics

Chemical	Sample Location	Year(s) Collected	N	Reported Mean	SE	Range	Reference	Comments
α-BHC	Alberta	1967-68	32	0.52 ppm	0.13	<0.001-3.42	Kadis et *al.*, 1970	3, 4
Heptachlor Epoxide	Alberta	1967-68	47	0.10 ppm	0.04	<0.001-1.22	Kadis et *al.*, 1970	3, 4
Dieldrin	Alberta	1967-68	47	0.10 ppm	0.04	<0.001-1.35	Kadis et *al.*, 1970	3, 4
p,p'-DDE	Alberta	1967-68	47	2.59 ppm	0.25	0.01-8.30	Kadis et *al.*, 1970	3, 4
p,p'-DDD	Alberta	1967-68	47	0.13 ppm	0.03	<0.002-5.15	Kadis et *al.*, 1970	3, 4
p,p'-DDT	Alberta	1967-68	47	0.82 ppm	0.12	<0.005-3.16	Kadis et *al.*, 1970	3, 4

See notes at end of Table 3.4d.

Table 3.4c Residue Levels in Human Liver Tissue (Wet Weight): Metals

Chemical	Sample Location	N	Reported Median	Range	Det. Freq. %	Detect. Limit	Reference	Comments
Cadmium	Kingston	44	1.8 mg/kg	0.4-6.7	100	0.02 mg/kg	Subramanian and Méranger, 1982	6
Cadmium	Kingston	72	1.8 mg/kg	0.1-9.0	100	0.02 mg/kg	Subramanian *et al.*, 1985	6
Cadmium	Ottawa	63	1.5 mg/kg	0.1-9.1	100	0.02 mg/kg	Subramanian *et al.*, 1985	6
Copper	Kingston	44	5.3 mg/kg	1.6-14.8	100	0.08 mg/kg	Subramanian and Méranger, 1982	6
Copper	Kingston	68	5.4 mg/kg	1.6-11.9	100	0.08 mg/kg	Subramanian *et al.*, 1985	6
Copper	Ottawa	66	4.9 mg/kg	1.0-12.8	100	0.08 mg/kg	Subramanian *et al.*, 1985	6
Lead	Kingston	71	0.4 mg/kg	≤0.1-1.6		0.1 mg/kg	Subramanian *et al.*, 1985	6
Lead	Ottawa	64	0.4 mg/kg	≤0.1-1.7		0.1 mg/kg	Subramanian *et al.*, 1985	6
Mercury	Kingston	72	0.05 mg/kg	0.01-0.34	100	0.002 mg/kg	Subramanian *et al.*, 1985	6
Mercury	Ottawa	62	0.05 mg/kg	0.01-0.37	100	0.002 mg/kg	Subramanian *et al.*, 1985	6
Zinc	Kingston	44	66 mg/kg	29-188	100	0.2 mg/kg	Subramanian and Méranger, 1982	6
Zinc	Kingston	68	67 mg/kg	25-183	100	0.2 mg/kg	Subramanian *et al.*, 1985	6
Zinc	Ottawa	62	56 mg/kg	20-138	100	0.2 mg/kg	Subramanian *et al.*, 1985	6

See notes at end of Table 3.4d.

Table 3.4d Residue Levels in Human Liver Tissue (Lipid Weight): Organics

Chemical	Sample Location	Year(s) Collected	N	Reported Mean	SE	Range	Reference	Comments
α-BHC	Alberta	1967-68	34	0.78 ppm	0.15	<0.001-3.47	Kadis et al., 1970	3, 4
Heptachlor Epoxide	Alberta	1967-68	50	0.19 ppm	0.07	<0.001-1.80	Kadis et al., 1970	3, 4
Dieldrin	Alberta	1967-68	50	0.25 ppm	0.08	<0.001-3.00	Kadis et al., 1970	3, 4
p,p'-DDE	Alberta	1967-68	50	3.04 ppm	0.31	0.01-9.00	Kadis et al., 1970	3, 4
p,p'-DDD	Alberta	1967-68	50	1.45 ppm	0.22	<0.002-7.52	Kadis et al., 1970	3, 4
p,p'-DDT	Alberta	1967-68	50	0.42 ppm	0.09	<0.005-2.65	Kadis et al., 1970	3, 4

Notes for Kidney and Liver Tables

1. Kidney Cortex.
2. Kidney Medulla.
3. Did not report whether values were corrected for recovery losses.
4. Did not report how means were calculated.
5. Sample collected in 1973.
6. Date of collection of sample was not reported.

APPENDIX

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Department of National Health and Welfare

Dr. Mike Whittle
Great Lakes Laboratory for
Fisheries and Aquatic Sciences
Department of Fisheries and Oceans

* Mr. David Fairbairn and Mr. Ron Shimizu served as chairpersons during the latter stages of this project.

Canada

Environment Canada Environnement Canada

Environment Canada
Communications Directorate
Ontario Region
25 St. Clair Avenue East, 6th Floor
Toronto, Ontario
M4T 1M2

Fisheries and Oceans Pêches et Océans

Fisheries and Oceans Canada
Communications Directorate
Bayfield Institute
867 Lakeshore Road
P.O. Box 5050
Burlington, Ontario
L7R 4A6

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